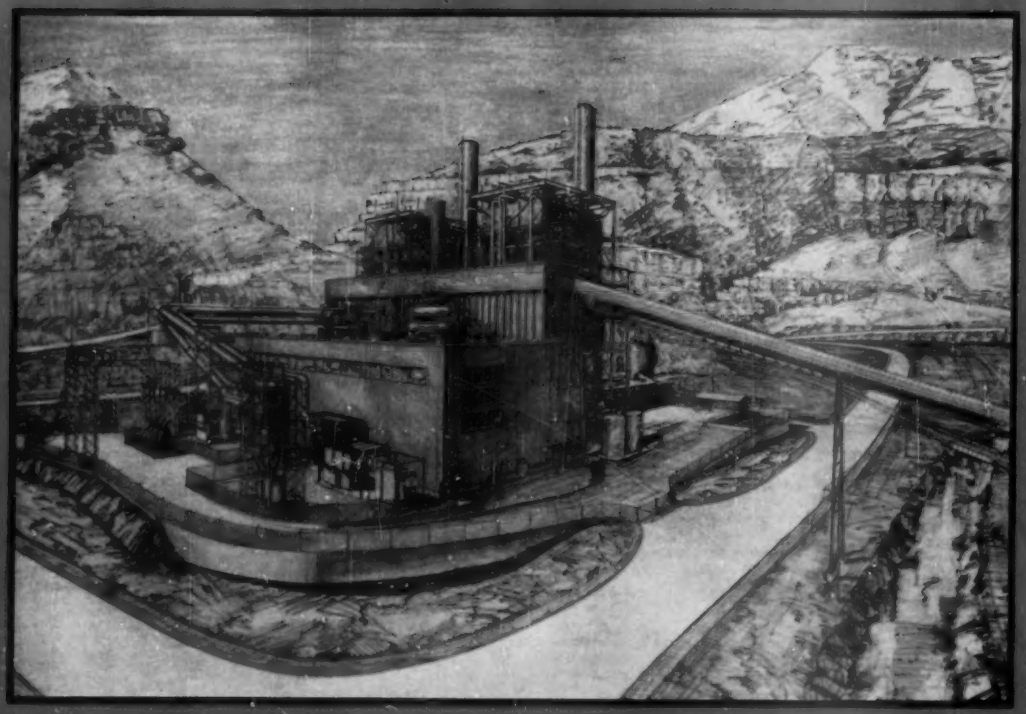
COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

July 1957



An architect's drawing of the Utah Power & Light Co.'s 100,000 kw second unit of Carbon Plant at Castle Gate, Utah.

Primary Approach to Servomechanisms

Eliminating Acid Dewpoint With Ammonia

Energy Resources and Our Future

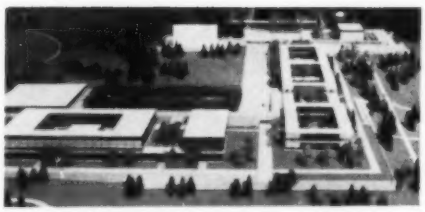
Steam Calorimetry

One of the three C-E LaMont Hot Water Boilers being installed at Forbes Air Base, Topeka, Kansas.

Maybe hot-water heating doesn't sound like a new development to you. But it may be news to you that water at very high temperatures – up to 470° F and 500 pounds pressure – is coming to the fore as an advantageous method of heating large areas.

A big factor in bringing this trend about is the C-E LaMont Controlled Circulation Hot Water Boiler. Using the same principle applied by C-E in many of the country's largest utility boilers, this new boiler provides a degree of temperature control that makes it the most attractive method of heating in many cases. Examples of highly successful applications are industrial plants, large institutions, air bases and other military installations.

There are many cases, of course, where steam may still be the best choice. But here is an important point: whichever may be best for you, C-E, with its complete line of boilers of all types, can supply the equipment best suited to your particular situation. And, Combustion's wide experience is available to you and your consultants in finding the right answer. For details on C-E high-temperature water boilers, write for Catalog HCC-2.



Model of the country's newest service school, the U. S. Air Force Academy at Colorado Springs, where five C-E Hot Water Boilers will serve living, academic and service areas. Recognition of this system's advantages is shown by the fact that this same type of equipment is in service or on order for such Air Force Bases as Dover, Portsmouth, Forbes and McGuire . . . for industrial plants like Convair Astronautics Div. of General Dynamics Co., The Cross Co., Erie Mining Co. and Marquardt Aircraft Co. . . . and for such institutions as the A. E. Smith High School in Riverview, Mich.

COMBUSTION ENGINEERING

Combustion Engineering Building
200 Madison Avenue, New York 16, N. Y.

B-991

ALL TYPES OF STEAM GENERATING, FUEL BURNING AND RELATED EQUIPMENT; NUCLEAR REACTORS; PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; SOIL PIPE

COMBUSTION

DEVOTED TO THE ADVANCEMENT OF STEAM PLANT DESIGN AND OPERATION

Vol. 29 **No. 1**

July 1957

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BPA

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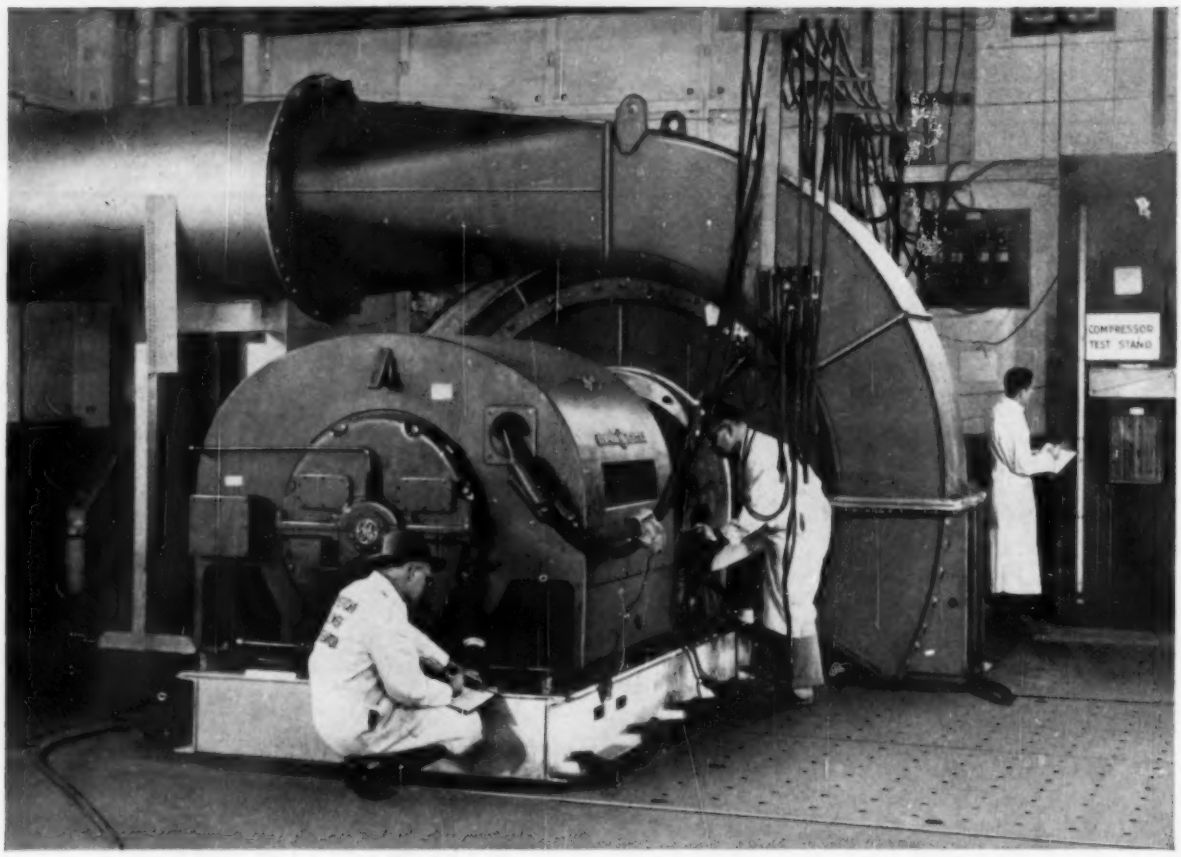
Here's the latest air-handling



LABORATORY TESTED CENTRIFUGAL COMPRESSOR DELIVERS 330,805 POUNDS OF AIR PER HOUR!

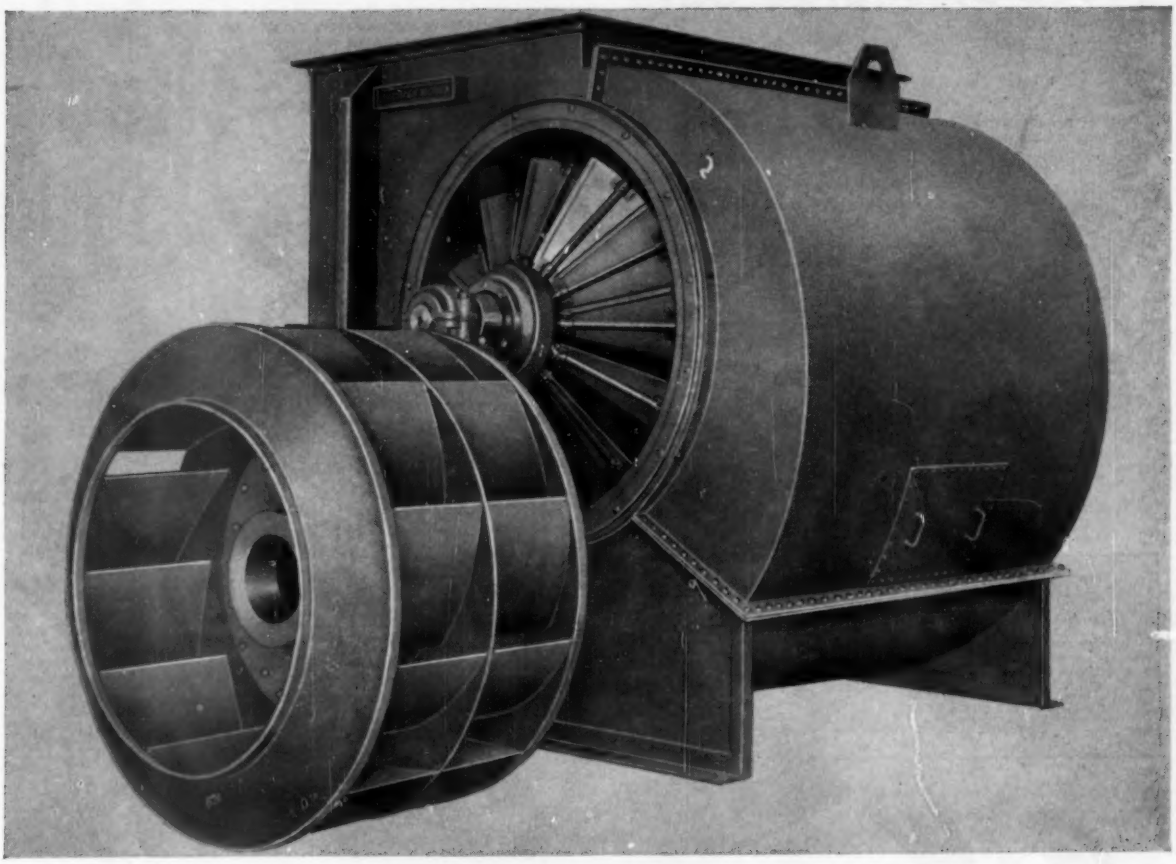
Cutaway of typical American Blower single-stage centrifugal compressor.

With the trend toward higher pressure requirements, American Blower has designed and built centrifugal compressors to furnish air for cyclone fired boilers. These compressors incorporate the use of a horizontally split, welded steel volute casing, variable inlet guide vanes, welded steel impeller of the shrouded type with impeller shaft supported by two journal bearings plus a Kingsbury thrust bearing arranged for positive forced-feed lubrication. This highly efficient compressor is driven by a 1000 HP, 1800 rpm, induction motor, delivers 330,805 pounds of air per hour at a static discharge pressure of 67.5 inches water gauge.

Like every American Blower single-stage centrifugal compressor – 30 to 2250 HP – this compressor has been completely tested in accordance with the A.S.M.E. Power Test Code. Such testing guarantees the mechanical operation and performance of all American Blower compressors.

Outstanding features: (1) Improved scroll-shaped casing design. (2) Unobstructed long diffuser passage converts velocity energy into pressure, contributes to quiet operation. (3) Annulus packing minimizes recirculation of gas around impeller inlet. (4) Removable inlet nozzle for accurate alignment of annulus packing. (5) Aero-dynamic design of impeller blades for high efficiency, long life. (6) Welded-steel baseplate "stress relieved" prior to machining.

equipment from American Blower

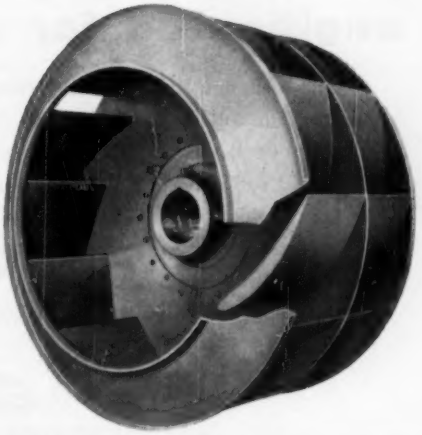


AIRFOIL FAN HAS ADVANCED DESIGN FOR HIGH EFFICIENCY, LOW OPERATING COST

Featuring a functionally designed airfoil blade, American Blower's improved Airfoil Fan is the industry's best in the non-overloading-horsepower type of centrifugal fan.

That's because smooth interworking of improved streamline inlets, wheel rims, and housing minimizes turbulence, resulting in higher efficiency, lower power consumption. The non-overloading-horsepower characteristic makes it possible to select a driving motor close to the fan horsepower.

Why not talk to an American Blower sales engineer about *your* requirements. His knowledge of air-handling applications can prove invaluable to you. Call our nearest branch office, or write: American Blower Division of American-Standard, Detroit 32, Michigan. In Canada: Canadian Sirocco products.



Special design of the airfoil blade and matching streamline inlet are the top features of American Blower Airfoil Fan. The dieformed, reinforced, and welded blades are extra strong, extremely efficient. Single- and double-inlet Airfoil Fans are available in many sizes, and for volumes up to 1,000,000 cfm.

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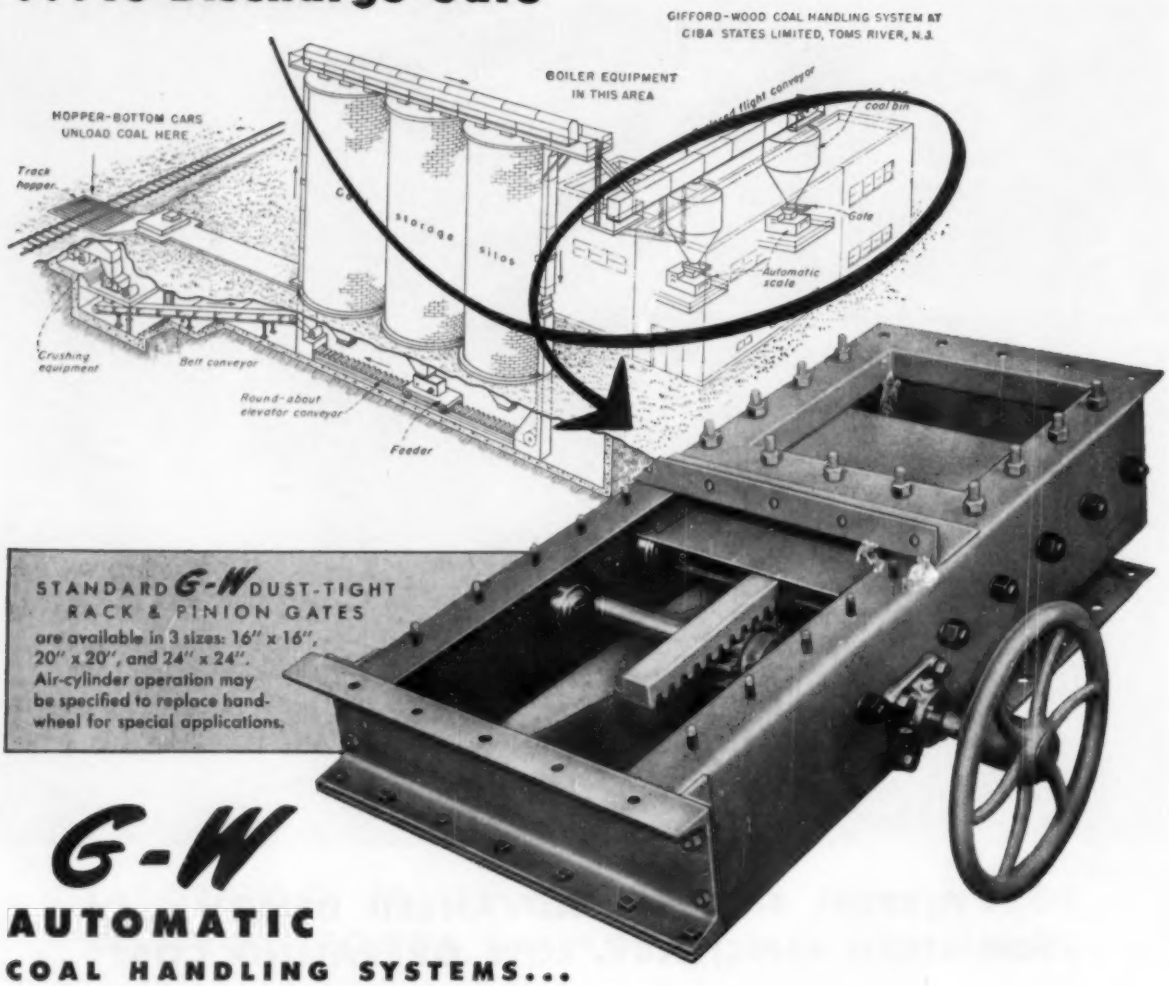
Division of AMERICAN-Standard

from Receiving Grate ... to Discharge Gate



STANDARD G-W DUST-TIGHT RACK & PINION GATES are available in 3 sizes: 16" x 16", 20" x 20", and 24" x 24". Air-cylinder operation may be specified to replace handwheel for special applications.

G-W AUTOMATIC COAL HANDLING SYSTEMS...

engineered for efficiency

This Rack and Pinion Gate is typical of G-W attention to engineering detail. It's the last piece of equipment in the complete G-W Automatic Coal Handling System in the huge new plant of Ciba States Limited, Toms River, N. J.

Through two of these gates pass all the coal used by this large processing plant. They absorb tons of pressure—day in, day out. Yet the rugged all-welded construction of the gate housing gives complete protection to all parts and traps all coal dust. Turning the handwheel moves the slide plate over sturdy roller bearings through a simple rack and pinion mechanism. Simple design?—Yes ... but the very efficiency of this gate lies in its *engineered* simplicity ... the Gifford-Wood way.

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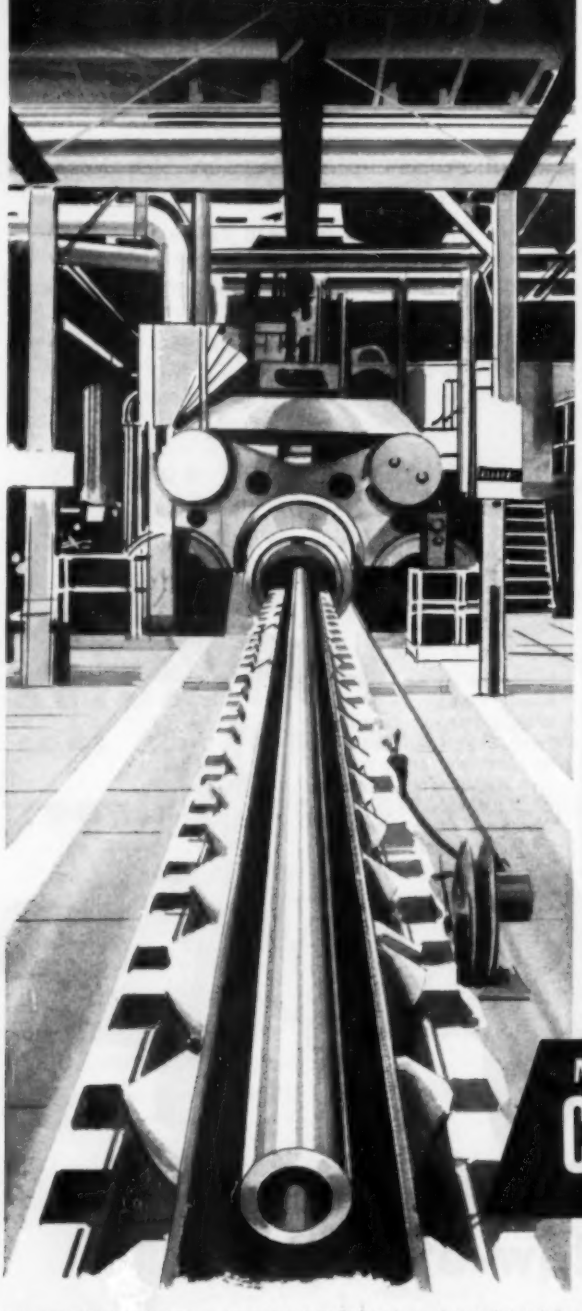

CURTISS-WRIGHT extrudes steels in shapes, lengths and sizes never before possible

Curtiss-Wright's Metals Processing Division is pushing steels into new uses for all industries. Shapes and sizes never before possible are being extruded in constantly increasing tonnages from alloy steels, stainless, titanium and other metals.

Starting with billets weighing up to 9000 pounds, the world's largest horizontal steel extrusion press moves the metal into shapes of virtually any profile that can be circumscribed by a 20-inch circle. Or, in a matter of seconds, the raw material may become heavy wall tubing up to 22 inches in diameter.

The 12,000 ton extrusion press and the complete facilities of Curtiss-Wright's Metals Processing Division are ready to go to work for you . . . to advance the design and production of metal products beyond the limitations of conventional equipment. Qualified engineering consultation available at all branch offices.

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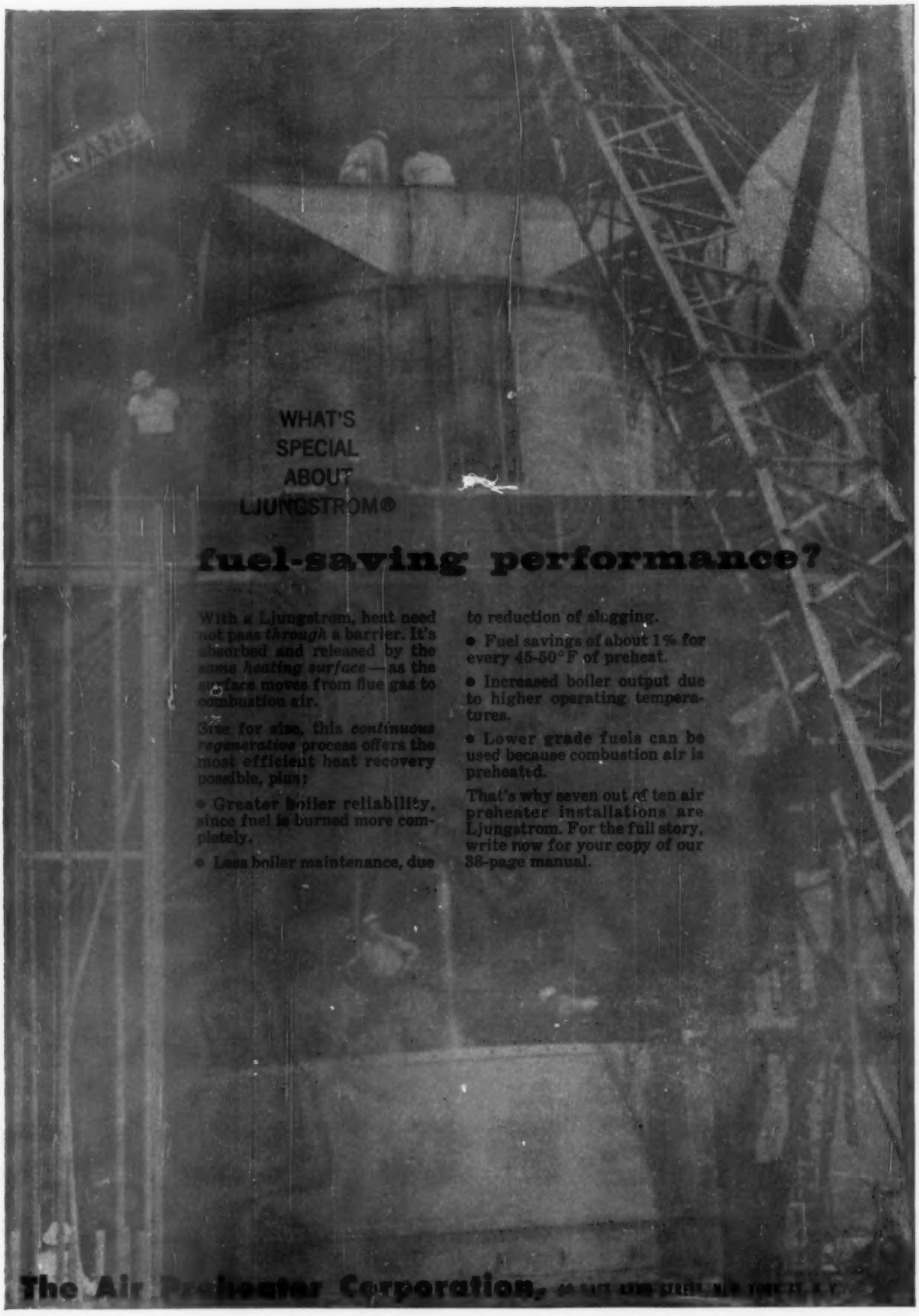
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fuel-saving performance?
With a Ljungstrom, heat need not pass *through* a barrier. It's absorbed and released by the *same heating surface*—as the surface moves from flue gas to combustion air.
Size for size, this *continuous regenerative* process offers the most efficient heat recovery possible, plus:
• Greater boiler reliability, since fuel is burned more completely.
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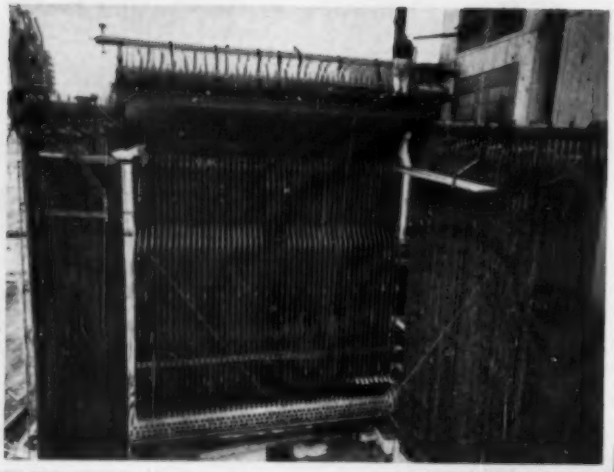
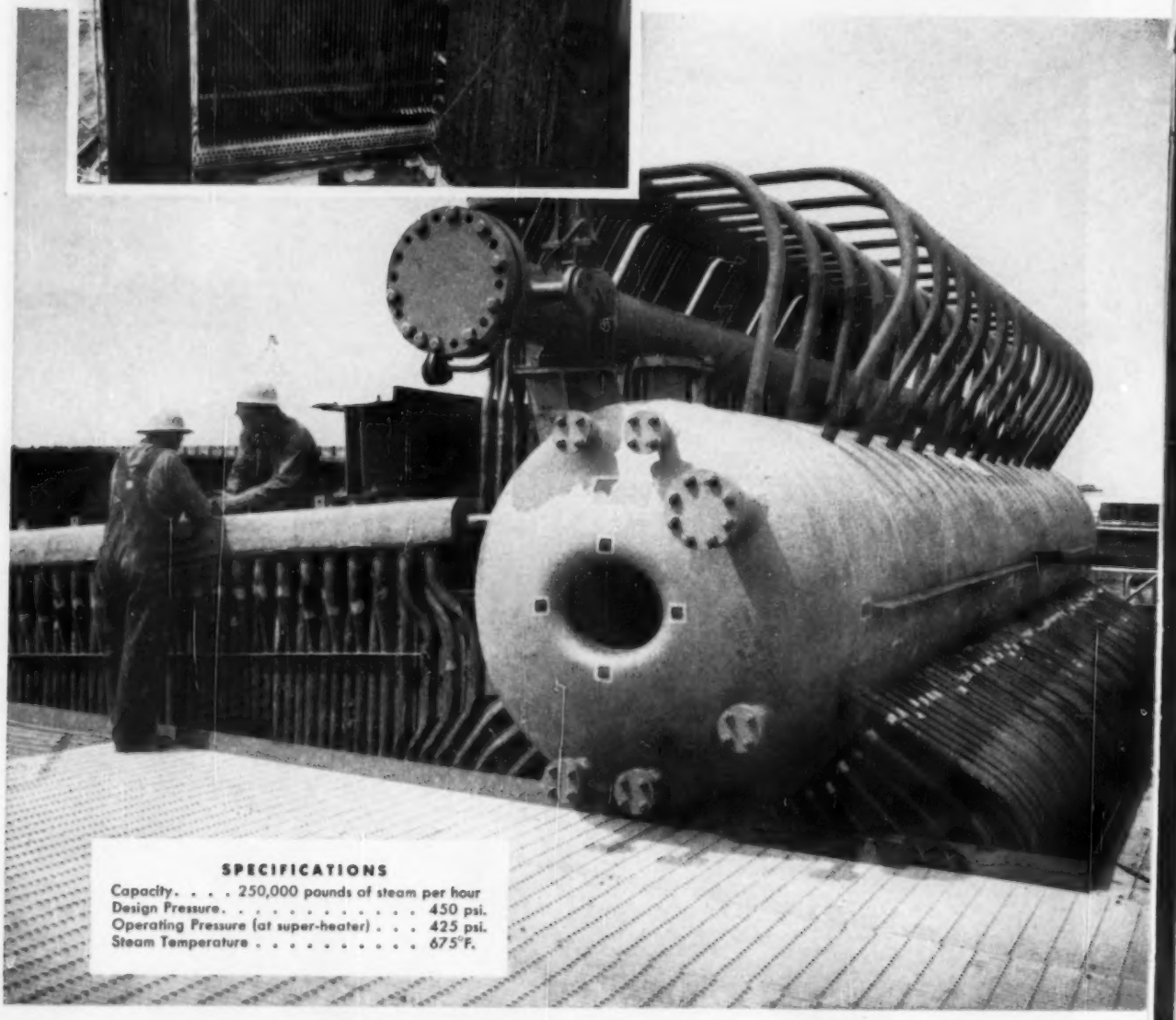
• Fuel savings of about 1% for every 45-50°F of preheat.
• Increased boiler output due to higher operating temperatures.
• Lower grade fuels can be used because combustion air is preheated.
That's why seven out of ten air preheater installations are Ljungstrom. For the full story, write now for your copy of our 38-page manual.
The Air Preheater Corporation,

Republic





SPECIFICATIONS

Capacity. . . . 250,000 pounds of steam per hour
Design Pressure. . . . . 450 psi.
Operating Pressure (at super-heater) . . . 425 psi.
Steam Temperature . . . . . 675°F.

REPUBLIC

REPUBLIC STEEL

World's Widest Range of Standard Steels

ELECTRUNITE Boiler Tubes

speed installation, assure top performance

"In Service on Time"! That is the target of Combustion Engineering, Inc., general boiler designers and erectors now working on the construction of a new boiler installation for the Magnolia Petroleum Company at Beaumont, Texas.

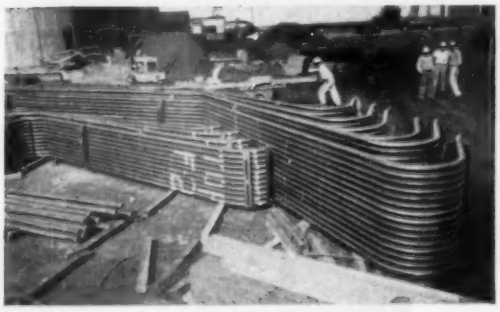
And past performance-records indicate Combustion Engineering will make this target, too, aided by the reliability, dependability, workability of Republic ELECTRUNITE® Boiler Tubes.

This Magnolia Petroleum Company installation has a design pressure of 450 psi., operating at 425 psi. at superheater outlet with a total temperature of 675°F., 250,000 pounds of steam per hour. Republic ELECTRUNITE meets every job requirement.

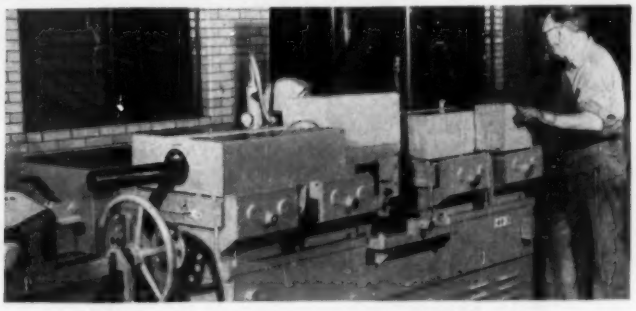
Each length of Republic ELECTRUNITE Boiler Tubing is hydrostatically or electronically tested to conform to the applicable ASTM specifications and the requirements of the ASME Boiler and Pressure Vessel Code, as well as local, state, and boiler-insurance requirements. In addition, Republic ELECTRUNITE is approved on an equal basis with tubes made by any other process up to 850°F. It is available for pressures over 2000 psi. in various sizes and wall thicknesses.

That is why more and more Republic ELECTRUNITE Boiler Tubing is specified by designers, engineers, and erectors for vital steam generating units operating in every industry and community field.

Your local Republic representative will be happy to supply you with all the facts on Republic ELECTRUNITE Boiler, Condenser and Heat Exchanger Tubing. Call today, or send coupon for literature.



Uniform ductility of Republic ELECTRUNITE Tubing makes bending to a precise contour easy. These units have been tack welded, shipped, are ready for final installation. Saves time in handling, transportation and erection.



SPECIFY FARROWTEST® — the most conclusive, nondestructive electronic tubing test in use today. Developed by Republic, FARROWTEST provides detector coils that can electronically spot defects in tube walls which would be hidden from routine test procedures.

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- ☐ Handy wall chart on care and maintenance of boiler tubes
- ☐ FARROWTEST brochure

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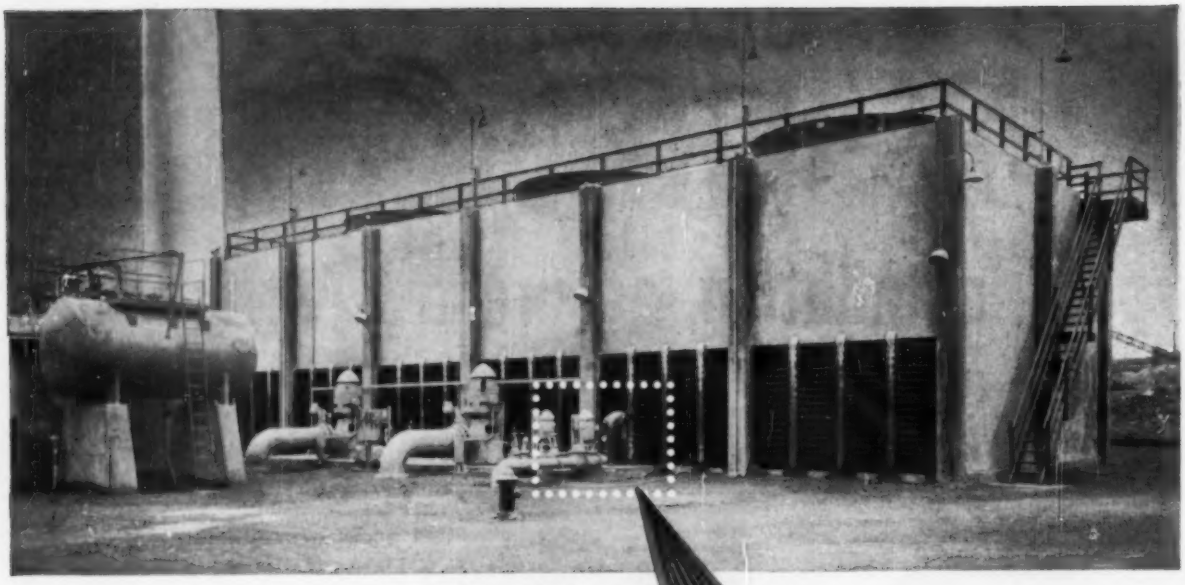
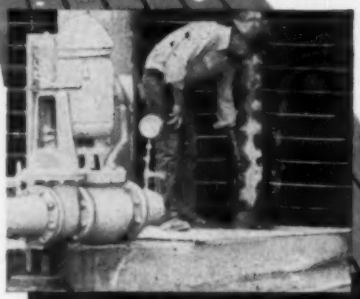


Unusual Cooling Tower

gets proven *Nalco* protection

This unusual cooling tower was built for the Riverside Cement Company at Oro Grande, California. The advanced design provides for concrete exterior walls which support and enclose fan units and redwood interior cooling vanes . . . The entire "working sections" of the tower can be repaired or replaced without affecting the structural strength of the shell. Nalco System Treatment protects this cooling system against scale and corrosion — has protected it effectively since it was first put in operation over two years ago. You can get the same complete water treatment protection, promptly, from Nalco. Write for details.



Method of feeding Nalco stabilizing treatment to this system is simplicity itself. Formula is supplied in ball form. Once each shift a perforated tube suspended in the tower basin is filled with balls which slowly dissolve in the cooling water.

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FOR COAL BUNKER NOSES,
CHUTES, HOPPERS, SPREADERS THAT MATCH
THE LIFE OF YOUR BOILER...

Take a comptroller's-eye view of Lukens Clad Steel

■ He'll see savings... and so will you! In coal handling equipment, Lukens clad steel puts a virtual stop to costly coal hang-ups and to damage from sulfuric acid in wet coal. Its durability is proved by installations more than 10 years old which show no measurable wear . . . ample evidence that it will match the life of your boiler.

Further savings accumulate from its ready fabrication, easy modification, and through freedom from down time and maintenance. The reasons: Lukens clad steel is not a lining, not a soldered-on surface, but a solid plate—one side corrosion resistant stainless steel permanently joined in a metallurgical bond to a rugged backing steel.

Lukens will help you and your fabricator select the proper types and gages to fit your needs. *Bulletin 740 will give you performance facts and production information.* For this bulletin, as well as the names of experienced coal handling equipment builders, write Manager, Marketing Service, 940 Lukens Building, Lukens Steel Company, Coatesville, Pennsylvania.

LUKENS ®

Helping industry choose steels that fit the job

Electronic Route to Lower

M. W. Kellogg's Digital Computer Permits More, Faster, Accurate Flexibility Analysis of Complex Main and Reheat Piping Systems

Control section of Kellogg's electronic computer.

KEEPING PACE with the increasingly critical pressures and temperatures of the modern steam-electric power plant are M. W. Kellogg's advanced techniques for pre-determining stresses and reactions of main and reheat piping. Most recent addition is a large magnetic drum digital computer, used to calculate forces, moments, deflections, rotations, and stresses in complex piping systems.

By enabling Kellogg engineers to undertake a far greater number of calculations in less time than ever before, electronic computation makes possible the ultimate or near ultimate piping system designs. Pipe runs can often be shortened without sacrificing required margins of safety; capital investment and maintenance costs reduced; operating efficiency increased.

A pioneer in flexibility analysis techniques, which include manual calculations, model testing, and a smaller electronic computer, Kellogg continues its pioneering in the power piping industry by the addition of this high speed computer to its New York engineering facilities.

A cordial invitation to see the M. W. Kellogg electronic computer at work is extended to consulting engineers and to engineers of power generating companies and their equipment manufacturers. Appointments may be made through the Sales Manager, Fabricated Products Division.

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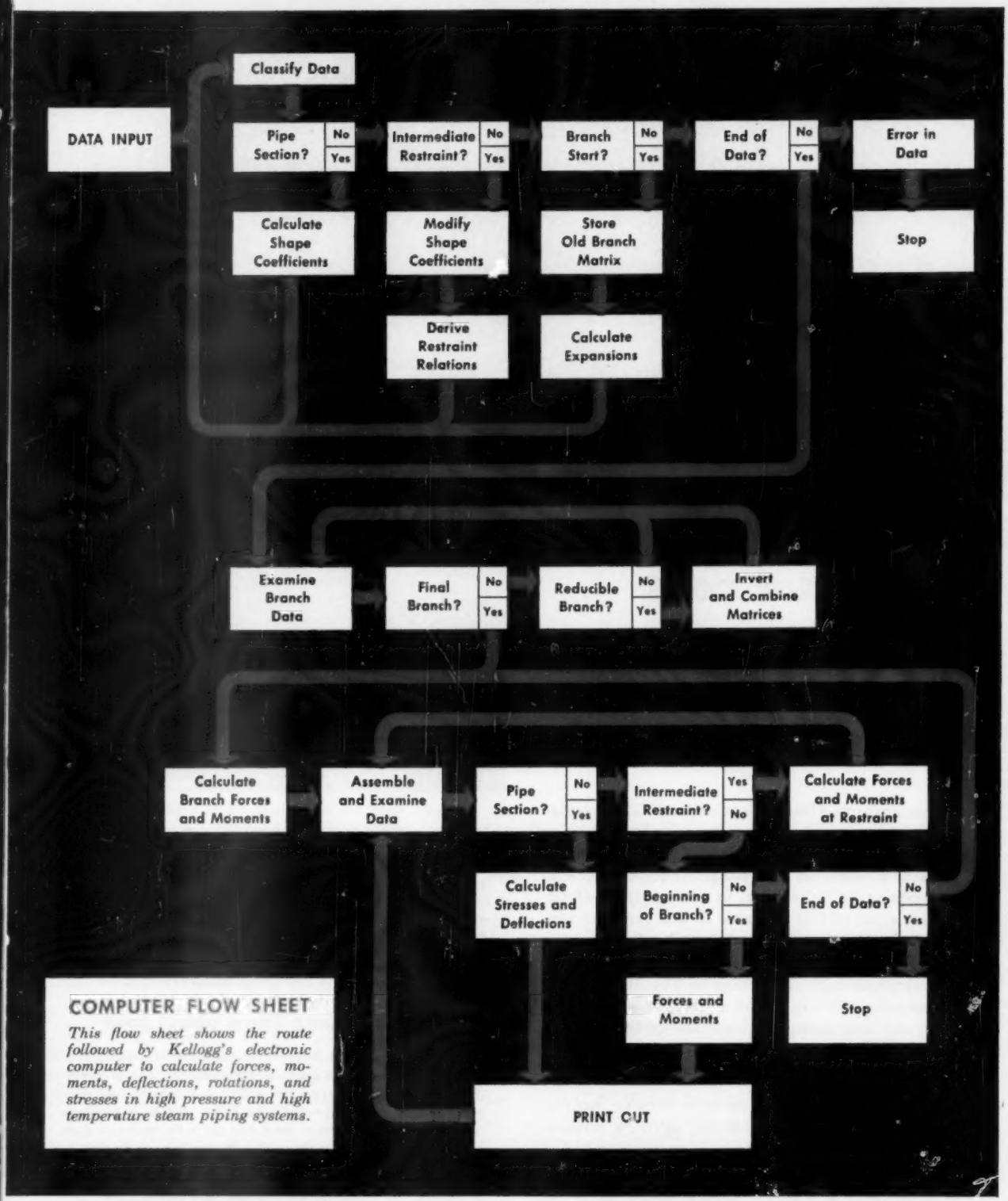
POWER PIPING—THE VITAL LINK

Steam Power Piping Costs



COMPUTER FLOW SHEET

This flow sheet shows the route followed by Kellogg's electronic computer to calculate forces, moments, deflections, rotations, and stresses in high pressure and high temperature steam piping systems.

Fuel cost survey proves coal best for Poinsett Hotel

The Poinsett Hotel, Greenville, S.C., recently decided to increase steam capacity by adding a new boiler in its power plant. At the time, management asked its consultants, The McPherson Company, of Greenville, to analyze costs of all three types of fuel available in that area. On the basis of cost per thousand pounds of steam, the other two fuels proved to cost 25% more than bituminous coal. According to The McPherson Company, "The net result of this study indicated that by continuing with the use of bituminous coal the owners would save on both the initial investment and on operating costs."

For additional case histories on burning coal the modern way or for technical advisory service, write to the address below.

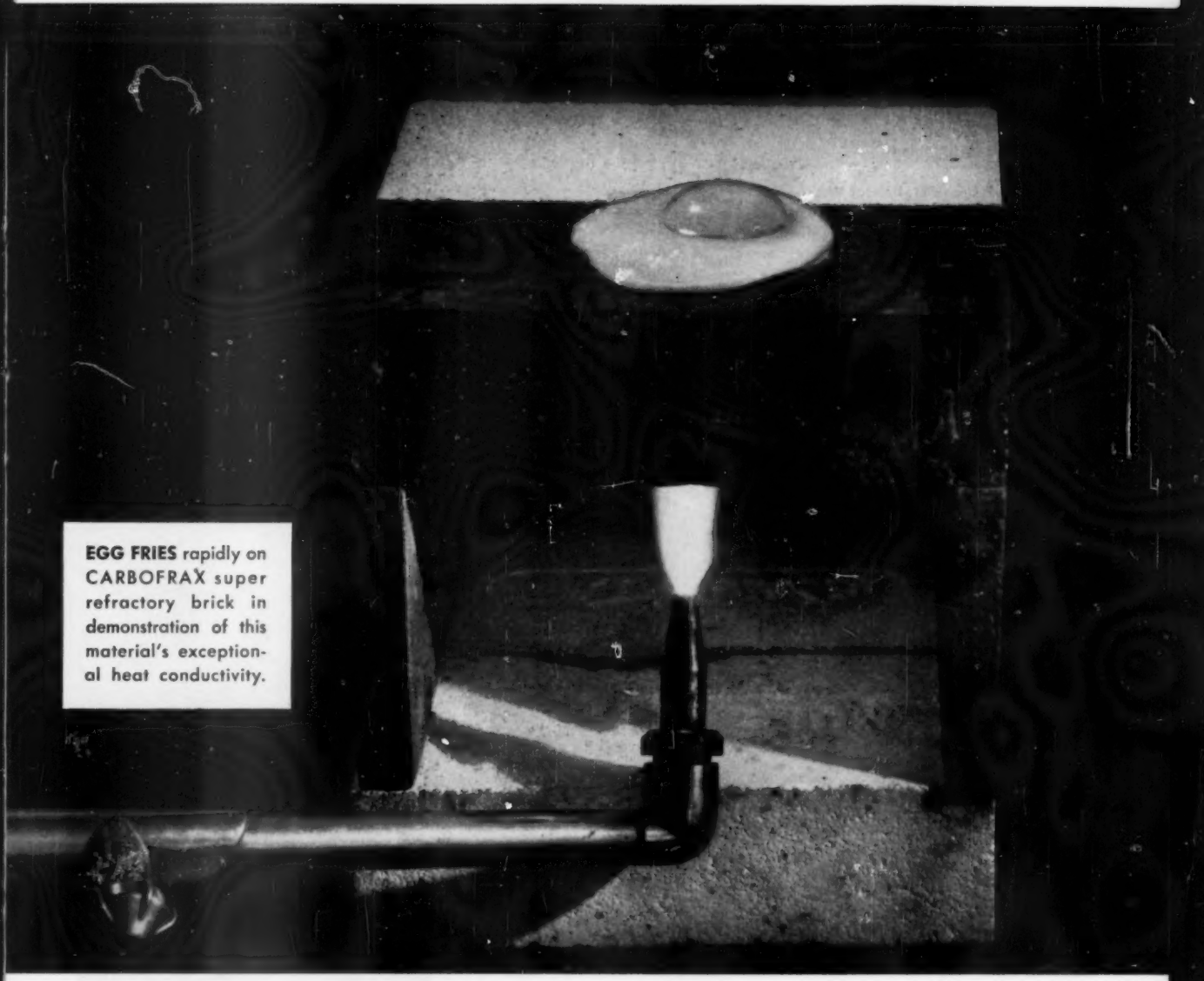
BITUMINOUS COAL INSTITUTE
Southern Building • Washington 5, D. C.

Consult an engineering firm

Designing and building hundreds of heating and power installations a year, qualified engineering firms can bring you the latest knowledge of fuel costs and equipment. If you are planning the construction of new heating or power facilities—or the remodeling of an existing installation—one of these concerns will work closely with your own engineering department to effect substantial savings not only in efficiency but in fuel economy over the years.

facts you should know about coal

In most industrial areas, bituminous coal is the lowest-cost fuel available • Up-to-date coal burning equipment can give you 10% to 40% more steam per dollar • Automatic coal and ash handling systems can cut your labor cost to a minimum • Coal is the safest fuel to store and use • No smoke or dust problems when coal is burned with modern equipment • Between America's vast coal reserves and mechanized coal production methods, you can count on coal being plentiful and its price remaining stable.



EGG FRIES rapidly on CARBOFRAX super refractory brick in demonstration of this material's exceptional heat conductivity.

Refractories for high **heat conductivity**

At 2200°F, CARBOFRAX® silicon carbide brick transmit 109 BTU/hr., sq. ft. and °F/in. of thickness. That is roughly 11 times the heat conductivity of fireclay and about 70% that of chrome-nickel steels. This conductivity becomes particularly valuable at the higher temperatures which these refractories alone can withstand (up to 3000°F without deformation; under certain conditions even higher). For example, there is increasing use of CARBOFRAX radiant tubes, muffles, retorts, and other structures which may operate at temperatures beyond the limitations of metals.

Seldom, however, are refractories called upon to provide heat conductivity alone. They must also be able to resist corrosion, spalling, cracking, heat shock and abrasion. Ability to carry heavy loads at high temperatures is another requirement often encountered. These are but a few of the conditions successfully met by super refractories pioneered by Carborundum. Among them, you are almost certain to find answers to your refractory and high-temperature problems. For help, fill in and mail this coupon:

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The Carborundum Company, Perth Amboy, N. J., Dept. E77

Please send me:

☐ Forthcoming issue of Refractories Magazine

☐ Bulletin on Properties of Carborundum's Super Refractories

☐ Here is a description of my high temperature problem. Can you help me?

Name _____ Title _____

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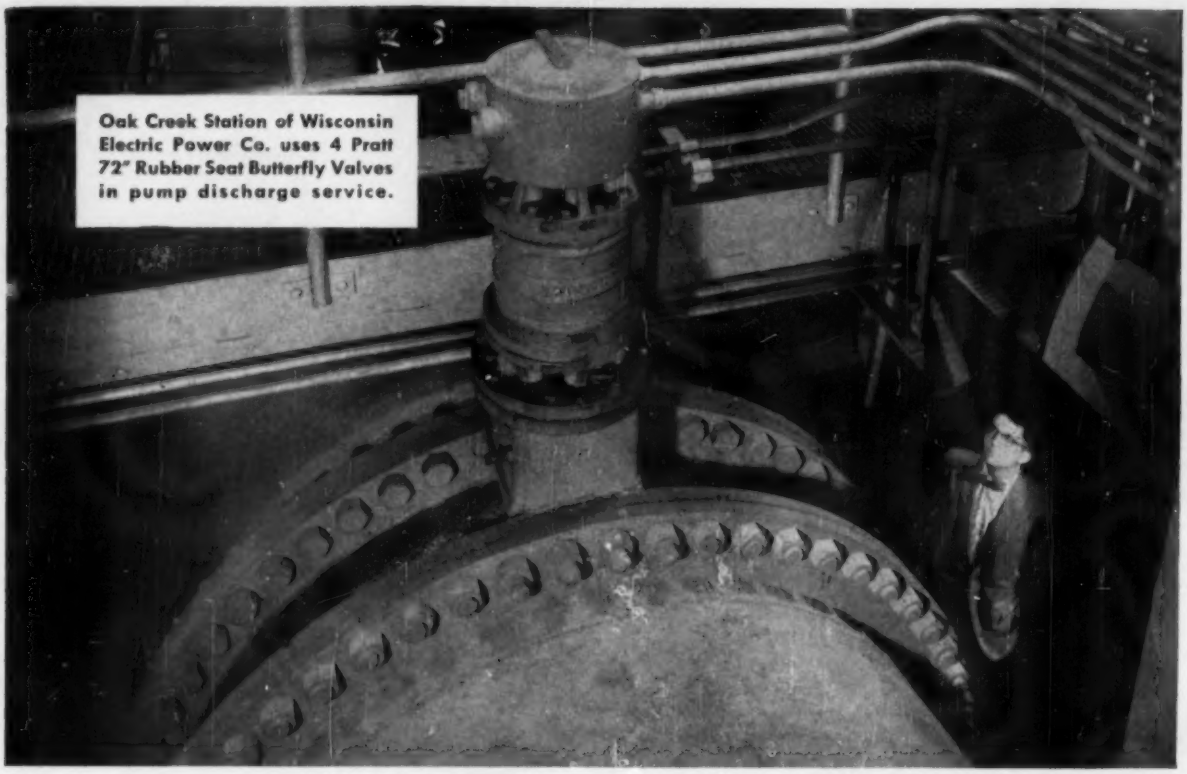
City _____ Zone _____ State _____



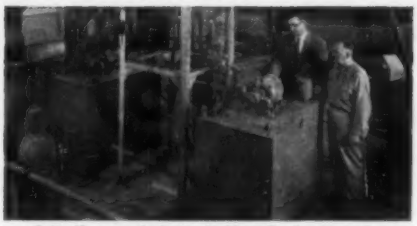
Oak Creek Station of Wisconsin Electric Power Co. uses 4 Pratt 72" Rubber Seat Butterfly Valves in pump discharge service.

MILWAUKEE...Pratt Butterfly Valves offer "two valves in one" for pump discharge

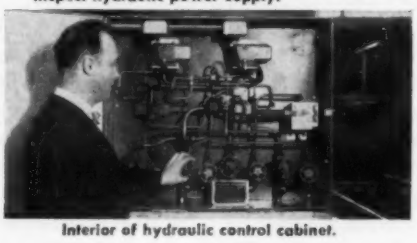
Pratt Rubber Seat Butterfly Valves in pump discharge service can be made to open and close in synchronization with pump operation, AND they close drop tight—combining, in a single valve, the functions normally achieved by separate shutoff and check valves. The simple combination of disc, shaft and efficient closure provides years of dependable performance without maintenance problems.

Pump discharge valves at Oak Creek Power Plant are hydraulically operated with oil motors. The electro-hydraulic system includes a bank of accumulators and complete auxiliary manual controls to permit operation under any emergency condition.

Pratt pioneered the use of rubber seat butterfly valves in power plants, and today offers the greatest aggregate experience on butterfly valving in the power field. For valve design—**with imagination**—see Henry Pratt.



Felix Kazmerchak, Ass't. Plant Engineer, and Ray F. Egebrecht, Pratt Representative, inspect hydraulic power supply.



Interior of hydraulic control cabinet.

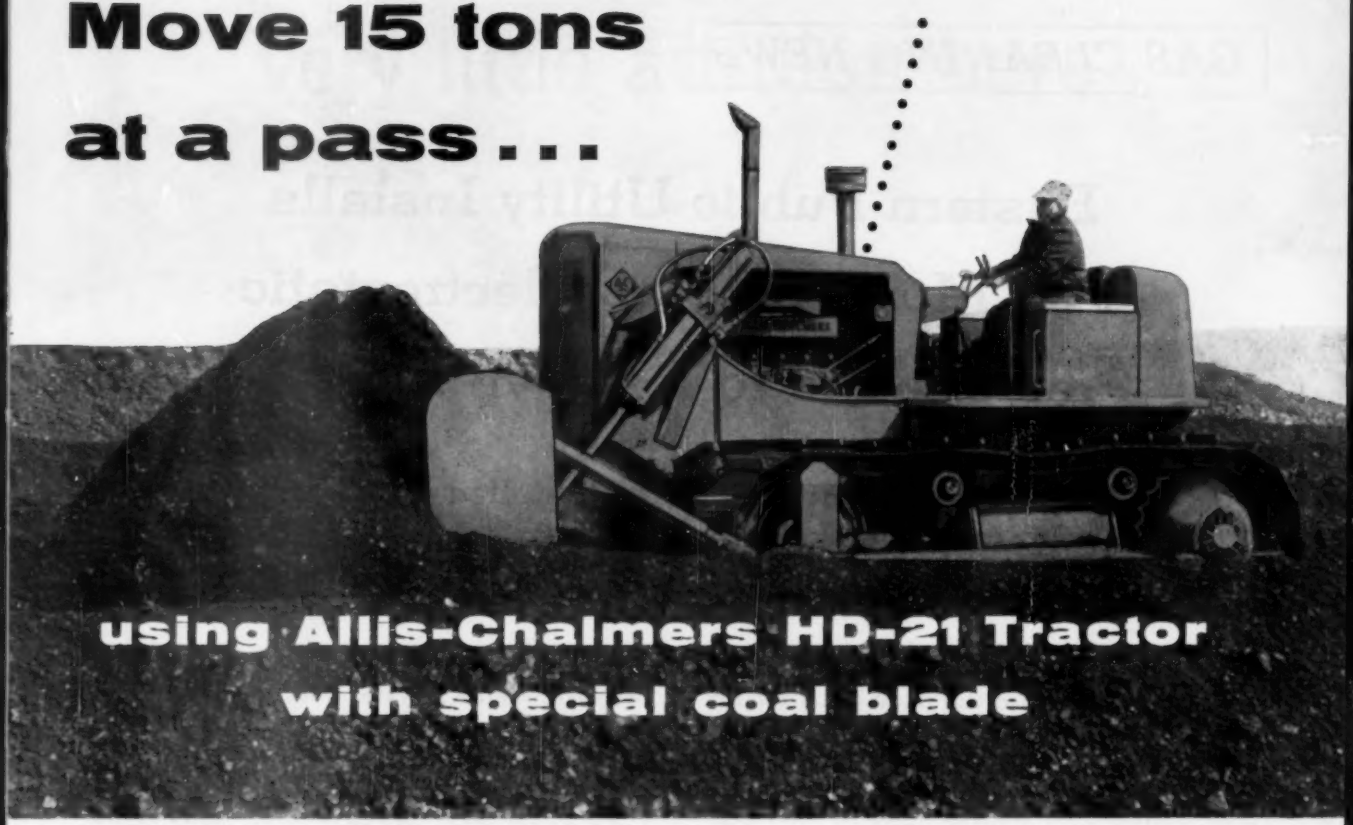
Have you sent for your copy?...of Pratt's 40 page **Manual of Rubber Seat Butterfly Valves.** Useful—contains latest pressure drop and flow data, conversion tables, butterfly valve theory and application. CATALOG B-2D.

HENRY PRATT

RUBBER SEAT Butterfly Valves

Henry Pratt Company, 2222 S. Halsted St., Chicago 8, Ill. Representatives in principal cities

Move 15 tons at a pass . . .



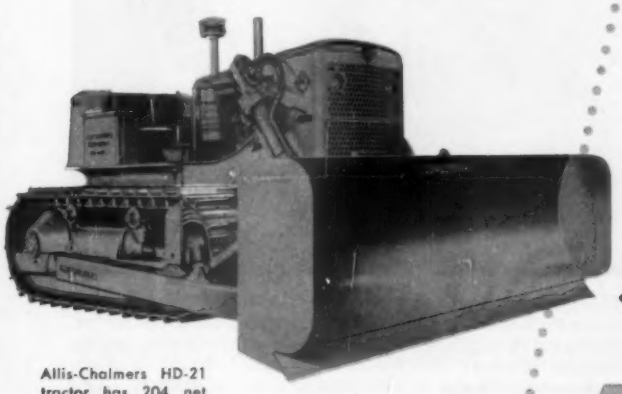
using Allis-Chalmers HD-21 Tractor with special coal blade

A special coal-handling blade now available for the Allis-Chalmers HD-21 fully uses the tremendous power and weight of this big tractor to move 15 tons of coal at a time.

HD-21 is coal-handling specialist— With its 204-hp diesel engine, the HD-21 has plenty of power for moving big loads. The hydraulic torque converter drive multiplies drawbar pull up to four and a half times, automatically accelerates to the highest traveling speed conditions permit. The torque converter permits climbing steeper grades, prevents killing the engine or digging in at soft spots, eliminates effort and time lost in shifting.

The compacting effect of a crawler tractor is well known. Through repeated trips over the coal pile, the 26-ton HD-21 and blade eliminate voids, prevent spontaneous combustion. The blade is shaped to move coal easily with a minimum of coal separation.

Dependability of the HD-21 is assured by Allis-Chalmers advanced design — Box-A Type Main Frame, one-piece steering clutch and final drive housing, straddle-mounted final drive gears, roller bearing truck wheels, through-hardened track rails — which also mean long life, less maintenance and faster repair when necessary.



Allis-Chalmers HD-21 tractor has 204 net engine hp, weighs 26 tons complete with cable or hydraulically controlled blade. Special coal blade has extra 56½-in. height and 15-ft length, plus boxed-in ends to carry 15 tons or more at a pass.

For additional information about the HD-21 tractor and coal blade — or about the other Allis-Chalmers tractors, tractor shovels, scrapers and motor scrapers — see your Allis-Chalmers construction machinery dealer or write direct to the company.

ALLIS-CHALMERS, CONSTRUCTION MACHINERY DIVISION
MILWAUKEE 1, WISCONSIN

ALLIS-CHALMERS

Eastern Public Utility Installs Two More Koppers Electrostatic Precipitators to Remove Fly Ash

Major Utility has installed 8 Koppers Electrostatic Precipitators since 1947

YEARS of cost-saving, highly efficient performance preceded this latest installation of Koppers Electrostatic Precipitators. During these years, this leading Eastern public utility was able to judge Koppers by on-the-job operation—the most positive proof of performance.

Proves Performance on the Job

Ten years ago, this company purchased its first two Koppers Electrostatic Precipitators for fly ash removal. Satisfactory performance and low maintenance costs justified the purchase of additional Koppers units that were installed in a total of 4 stations. The eight units furnish highly effective, trouble-free operation in a varying range of CFM capacities.

Supplies a Wide Range

The eight Koppers Electrostatic Precipitators serve boilers ranging in capacity from 570,000 #/hr to 950,000 #/hr. Guaranteed efficiency runs as high as 98%, depending on the need of each application. This ability to engineer for a wide range of capacities enables Koppers to satisfy the needs of each station.

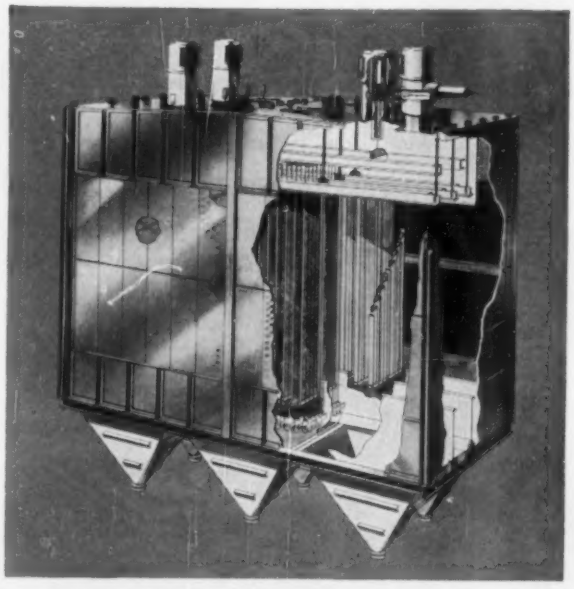
Meets Individual Plant Needs

Koppers custom-designs each Electrostatic Precipitator. Koppers units remove boiler fly ash before the flue gas is discharged from the stack. In designing Electrostatic Precipitators, Koppers utilizes its knowledge of the characteristics of various coals, types of boilers and methods of firing.

Backed by Know-How

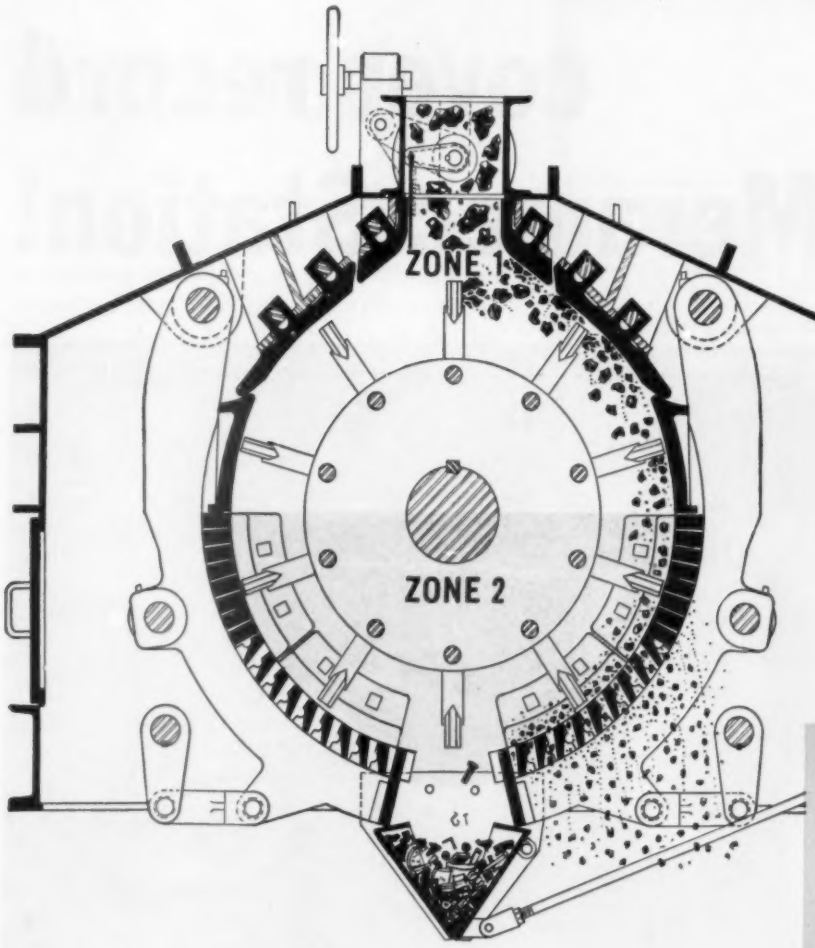
Koppers gas cleaning experience goes back 75 years. This experience is backed up by extensive research facilities at Verona, Pa., and Baltimore, Md. From this experience and research has come gas cleaning equipment for all sizes and types of plants.

Get the most out of your gas cleaning dollar. Write KOPPERS COMPANY, INC., Metal Products Division, Industrial Gas Cleaning Dept., 4407 Scott Street, Baltimore 3, Maryland.



This cutaway photo of a Koppers Electrostatic Precipitator shows shell, vibrators, and collecting and discharge electrodes. The actual design and arrangement of elements vary widely because Koppers Electrostatic Precipitators are custom-engineered to fit the requirements of each installation.

very little attrition here



less hammer and cage wear

Take a careful look at the illustration above. See how most of the size reduction of the coal takes place in zone 1 by free air impact, breaking along the lines of natural cleavage. Only after particle size has been greatly reduced does the coal reach zone 2, where hammers force it through the screen bars. Due to several adjustable features the operator has the option of various product sizes, making this the ideal coal preparation crusher for stokers, pulverizers or cyclone furnaces. Parts wear and power consumption are held to a minimum. And remember, the reversible feature greatly increases hammer life and eliminates down time and labor cost of manually turning hammers.

PENNSYLVANIA

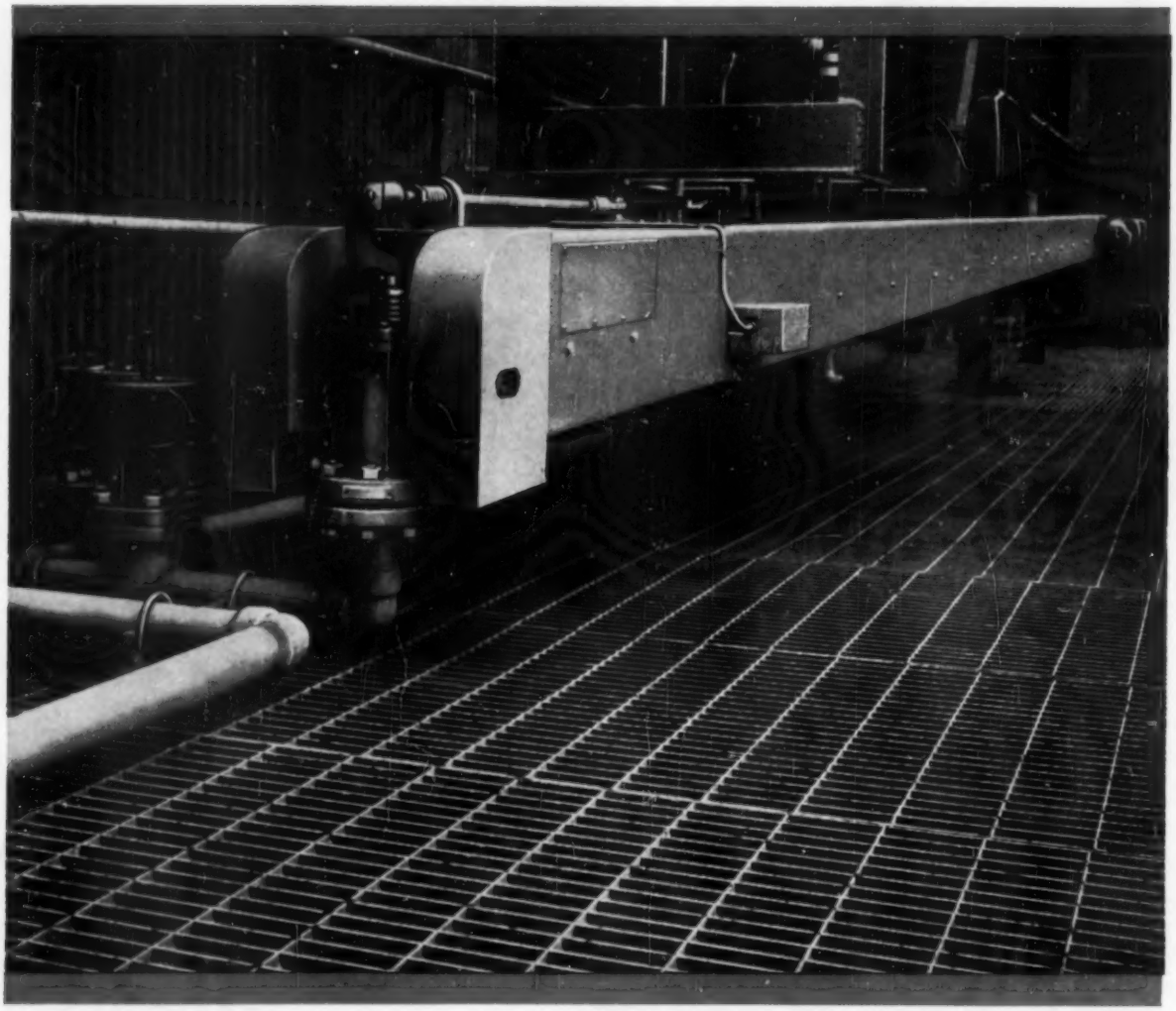
REVERSIBLE HAMMERMILL

PENNSYLVANIA CRUSHER DIVISION

Bath Iron Works Corporation • West Chester, Penna.

PE-209

Vulcan T-30 long cover record at Meramec Station!



This Vulcan T-30 long retractable soot blower has been in operation on Unit 1 at Meramec Station since May, 1956. Fuel for the Combustion Engineering boiler is pulverized coal. Burners are arranged for tangential firing and can be tilted for superheat control.

C-3447

retracts distance

A Vulcan T-30 long retractable soot blower is reaching more than 35 feet between two banks of the pendent secondary superheater on Boiler No. 1 in Meramec Station of Union Electric Company of Missouri. This Vulcan T-30 requires only one outboard hanger to support the extra-rugged framework. Lance travel and rotation are non-synchronized through two driving motors to produce a multi-helix cleaning path to cover different areas of the tube bank while extending and retracting.

Performance of this Vulcan T-30, which is located at the furnace exit where temperatures average 1910 degrees F., led to the selection of Vulcan T-30 blowers with 36-foot travel, RW-3E wall deslaggers and E-4-E rotaries—all under automatic-sequential control—for Meramec's new Unit 3, a Foster Wheeler boiler with separate furnaces, rated at 1,850,000 pounds per hour at 2150 psig and 1010 degrees F., with reheat to 1010 degrees F.

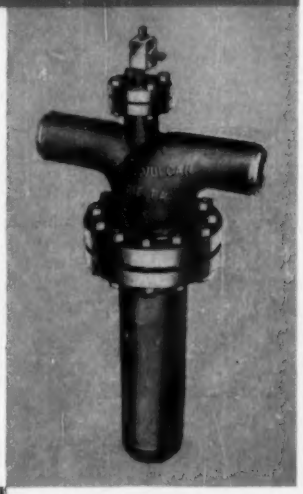
Whether your boiler is large or small, power or process, modern Vulcan soot blowers will help keep it operating at peak efficiency. Your Copes-Vulcan representative has the ideas, information and experience to help you choose the system best suited to your needs.

COPES VULCAN

BLAW-KNOX

COPES-VULCAN DIVISION
BLAW-KNOX COMPANY
ERIE 4, PENNSYLVANIA

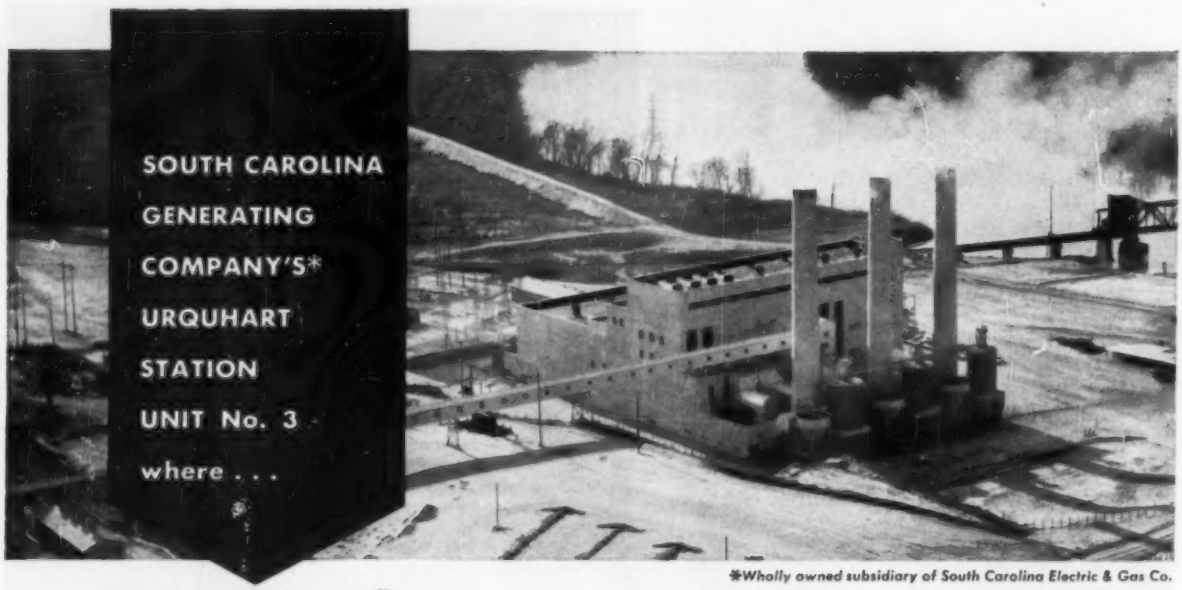
C-V NEWS NOTES



Copes-Vulcan Steam-Assist Desuperheater meets all specifications for conventional steam-atomizing type, yet normally uses assisting steam only on light loads where control is most difficult. Furnished with carburetor body as shown, or for in-line installation. Simple mechanical-atomizing types are also available. Bulletin 1024-A.

Unlimited pressures and sizes up to 16-inch, plus simplified design, are features of the new Copes-Vulcan Types CV-D and CV-P valves. Either diaphragm or piston types are available for pressure, temperature or liquid level control. Bulletin 1027.

Bulletin 1030 illustrates and describes the Vulcan T-30 long retractable soot blower, now successfully operating in temperatures up to 2150 degrees F. (radiant). Your Copes-Vulcan representative can give you a copy, or write direct to the factory.



*Wholly owned subsidiary of South Carolina Electric & Gas Co.

REPUBLIC *Automatic* COMBUSTION CONTROLS *Anticipate* FUEL-AIR-WATER REQUIREMENTS!

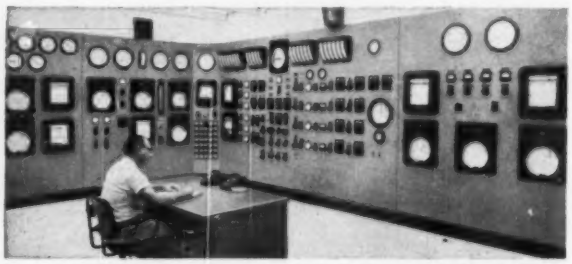
● Adjusts fuel, air and water as steam flow changes ● Makes follow-up adjustment of header pressure and water level if needed ● Prevents (rather than corrects) most pressure, level and temperature fluctuations before they happen!

Planned expansion of power in the Southeastern United States is typified by the addition of Unit #3 to South Carolina Generating Co.'s Urquhart Station. Rated capacity of the steam generator is 700,000 lb/hr at 1825 psi, superheated to 1010 F and reheated to 1010 F. Designed by Gilbert Associates, Urquhart #3 is modern in performance as well as appearance.

REPUBLIC's "Electronic Master" combustion control and triple-element feedwater control permit firing of pulverized coal, natural gas, or both at once without fluctuation of header pressure or water level. This system starts adjusting fuel, air and water as soon as steam flow changes perceptibly, not waiting for either drum level or header pressure to change.

If either of these factors change despite the preliminary adjustment, the change will be very small and will be offset immediately by a follow-up control that modulates the existing control signal. Since the flow of flue gas is held in such close proportion to the steam flow, temperature at the superheater outlet is held very close to a constant 1010 F despite load swings.

This advanced control system is a logical partner to the advanced thinking apparent throughout Urquhart #3. The quick action of electronic control added to the traditional reliability and power of pneumatic actuation produces a stable, accurate, dependable automatic system. And any one or all of the automatic control functions can be cut out at will to permit substitution of remote manual control at any time. Manual controls include indicators for electronic loadings of the regulators and positioners as well as position and rate of response indicators.



Control room of Urquhart Station's modern Unit #3.

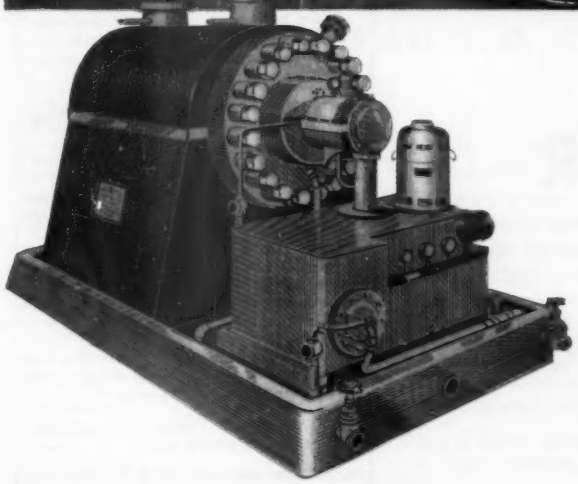
NEED HELP on "Early Stage" Planning?

Remember that Republic, too, is planning ahead. To get the latest information on developments that will effect control in your future power or processing plant, contact the REPUBLIC Engineering Department as soon as such help would be beneficial.

REPUBLIC FLOW METERS COMPANY

A Subsidiary of Rockwell Manufacturing Company

2240 Diversey Parkway, Chicago 47, Illinois



PACIFIC BOILER FEED PUMPS

CONTINUOUS POWER...a *must* in Southern California Edison's giant El Segundo steam station. Three Pacific boiler feed pumps were placed in operation for unit No. 1 in 1955. Two more Pacific pumps were selected and went on the line for unit No. 2 in 1956. The combined generating capacity of the two units is 350,000 kilowatts. These Pacifics, each delivering 685,000 lbs./hr. of 360°F. feed water at 2350 PSIG, unfailingly serve Southern California Edison's El Segundo plant needs. Whenever continuous boiler feed service is an absolute must... then nothing but the best, most dependable service will do... Pacific Boiler Feed Pumps!

Write for Bulletin 122

PACIFIC PUMPS INC.

HUNTINGTON PARK CALIFORNIA

Offices in all Principal Cities

ONE OF THE GREATER INDUSTRIES

PACIFIC®

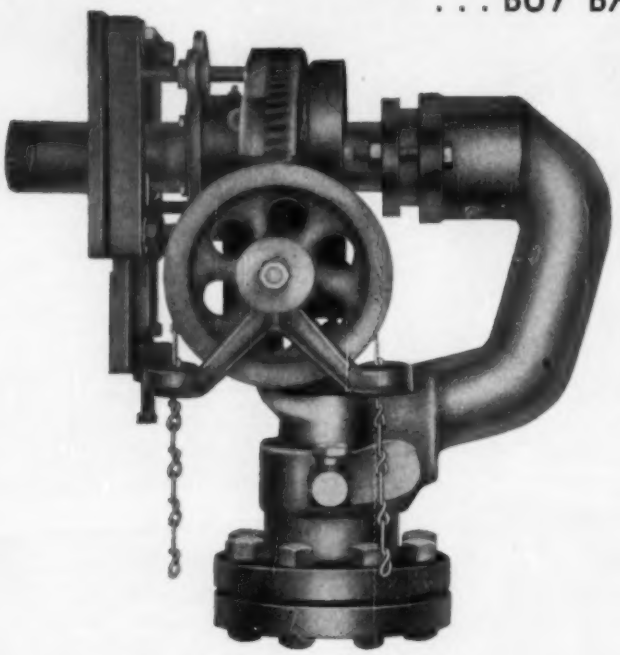
BF-26

THE BAYER CO.

MANUFACTURERS OF BAYER SOOT BLOWERS

For Highest First and Final Value

. . . BUY BAYER!



BAYER

Balanced Valve

SOOT CLEANER

Bayer's single-chain design compels perfect in-step operation of valve and element. Operation is positive, definite, assuring a full flow of steam for efficient cleaning.

When the operator pulls chain, the cam-actuated, quick-action balanced valve is opened. By continued pulling of the chain, worm drive slowly rotates element over cleaning arc. When element reaches end of cleaning arc, valve automatically closes.

Minimum steam consumption—low maintenance. Every detail is engineered, built for long life, efficient performance at high temperatures and high pressures.

More than 30,000 boilers are Bayer equipped. More than 45 years' successful, specialized experience assures you investment economies in Bayer equipment.

QUALIFIED LOCAL ENGINEERING SERVICE—Your Bayer representative is an experienced engineer, well qualified to take care of any service needs in connection with Bayer Soot Cleaners. He is available when you call upon him and will gladly render any service required.

All These Mechanical and Operating Advantages are available in

The BAYER *Balanced Valve* SOOT CLEANER

1. **Sound engineering, workmanship, and materials of the best.**
2. **An organization of over 45 years' experience, capable and willing to render service at all times.**

SINGLE CHAIN: Valve and element controlled by a single chain.

VALVE BODY: Rugged construction, built to last. Short and ample steam passage giving very small pressure drop.

ORIFICE PLATE VALVE: For high pressure service, each head may be controlled by an orifice plate valve through which pressure is adjusted for each individual element.

STUFFING BOX: Due to maintenance of perfect alignment on swivel tube, packing needs little attention. Stuffing box is in full view, readily accessible.

AIR SEAL: Has machined surface on wall sleeve and spring-held floating seal to prevent air in-leakage.

HEAD BEARINGS: There are two main bearings, an outboard and an inboard bearing for the swivel tube to maintain alignment.

THRUST BEARING: Ring type thrust bearing takes the load.

VACUUM BREAKERS: Two vacuum breaker air valves, or one valve and a signal whistle above each valve, to prevent suction of boiler gases into valve and piping.

ELEMENT OPERATION: With the Bayer element operation, balanced valve is opened just as element rotates, giving FULL pressure over entire cleaning arc. Full steam pressure insures thorough cleaning. Balanced valve saves wear of valve parts. With any type of poppet valve, this is important...ask any operator.

BLOWING ARC: Valve cams automatically regulate cleaning arc.

REDUCTION GEARS: 24 to 1 gear ratio gives slow rotation for good cleaning.

FLANGED PIPE CONNECTION: Operating head is connected to supply pipe by flanges and through bolts, or high tensile studs and nuts.

THE BAYER CO.

St. Louis, Mo.

Unretouched photo showing typical return line corrosive action resulting from carbonic acid and dissolved oxygen in condensate.

BREAKING DOWN WITHIN

This section of pipe looks like new—on the outside. But take a look inside. Grooving action caused by carbonic acid and deep pitting, the result of dissolved oxygen attack, have almost completely penetrated the pipe wall.

Dearborn FILMEEN* prevents such destruction. FILMEEN forms a protective, non-wettable barrier between treated steam, or condensate, and metal pipe surfaces. By preventing the carbonic acid and dissolved oxygen from coming into contact with the metal, FILMEEN assures corrosion-free lines. FILMEEN is only one of many Dearborn water conditioning products scientifically developed to control specific corrosion problems. Others eliminate scale, sludge, carry-over and similar difficulties.

Power engineers in leading industrial and commercial plants place their confidence in Dearborn's 70 years of experience in water chemistry. They have found the answer to the demand for complete plant protection in Dearborn Supervisory Service—a properly balanced water conditioning program which combines quality products with correct, technically supervised control methods and test procedures.

Let a Dearborn Engineer survey your plant and recommend the type of water control program best suited to your requirements.

**FILMEEN is the trade-mark of a corrosion-inhibiting compound patented and produced exclusively by Dearborn Chemical Company. U.S. Pat. No. RE 23614.*

Dearborn®

...a leader in water conditioning and corrosion control for 70 years

Dearborn Chemical Company
Merchandise Mart Plaza, Dept. COM, Chicago 54, Ill.

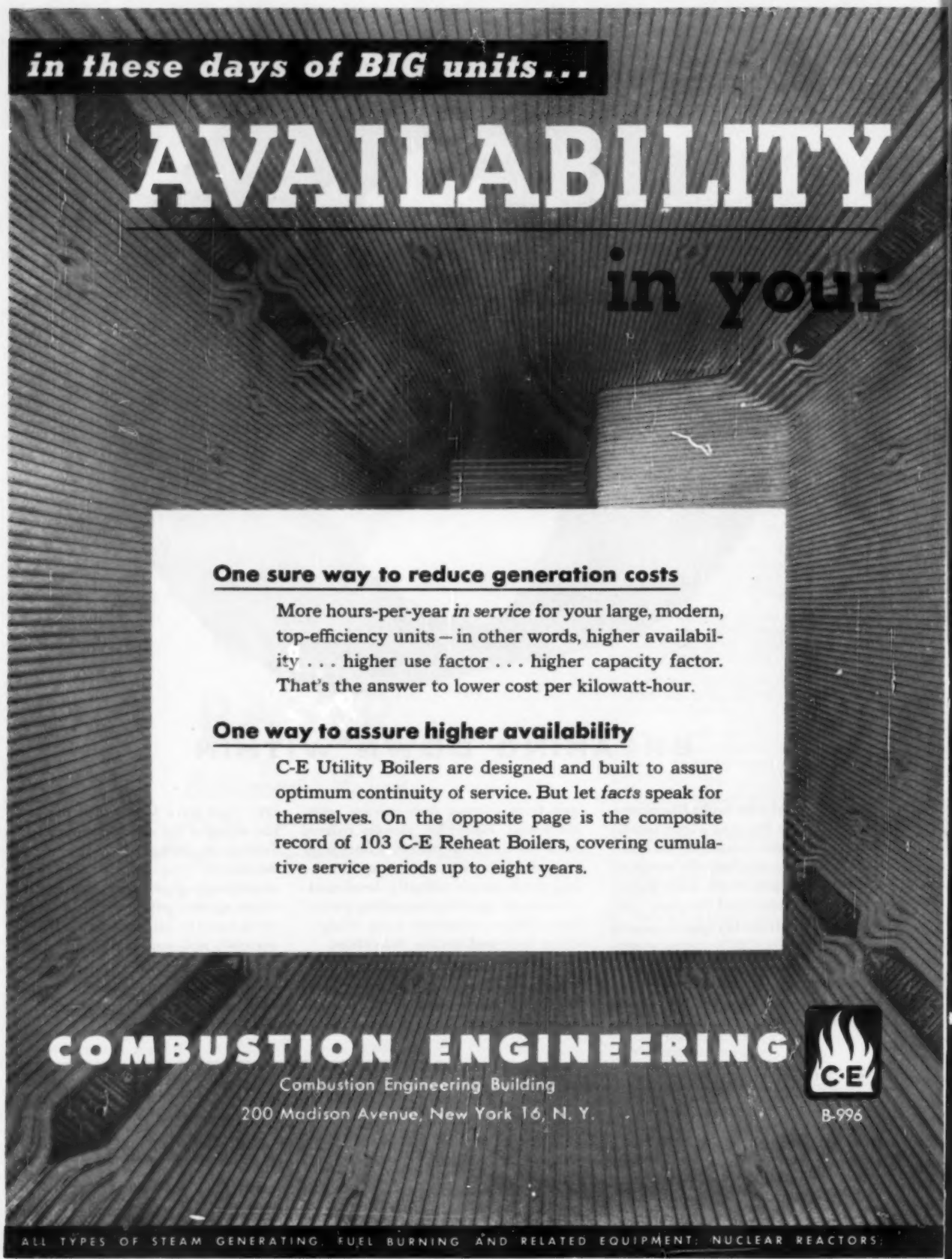
Gentlemen: ☐ Have a Dearborn Water Conditioning Engineer call.
☐ Send me complete information on Dearborn Water Conditioning Program.

Name.....*Title*.....

Company.....

Address.....

City.....*Zone*.....*State*.....


in these days of BIG units...
AVAILABILITY
in your
One sure way to reduce generation costs
More hours-per-year *in service* for your large, modern, top-efficiency units – in other words, higher availability . . . higher use factor . . . higher capacity factor. That's the answer to lower cost per kilowatt-hour.
One way to assure higher availability
C-E Utility Boilers are designed and built to assure optimum continuity of service. But let *facts* speak for themselves. On the opposite page is the composite record of 103 C-E Reheat Boilers, covering cumulative service periods up to eight years.
COMBUSTION ENGINEERING
Combustion Engineering Building
200 Madison Avenue, New York 16, N. Y.
C-E
B-996
ALL TYPES OF STEAM GENERATING, FUEL BURNING AND RELATED EQUIPMENT; NUCLEAR REACTORS

is the No. 1 factor generation costs

OPERATING RECORD OF 103 C-E REHEAT BOILERS

The first of these boilers was placed in service in 1949. By the end of 1956, one hundred and three units were "on the line." Significant data concerning these boilers which, in this report, are all private utility units, are summarized below.

Number of Units	103
Total Capacity — Mw	11,265
Average Capacity per Unit — Mw	109
Total Boiler Time — Hours	2,635,524
— Years	307

AVERAGE AVAILABILITY Boiler — **95.78%**

(In service or available. Not considered available while down for inspection or repair, or while in process of starting up or shutting down.)

AVERAGE USE FACTOR Boiler-Turbine — **90.40%**

(Ratio of in-service hours to total hours — all outage not necessarily chargeable to boilers.)

AVERAGE CAPACITY FACTOR Boiler-Turbine — **89.60%**

(Ratio of average hourly output — net kw — to rating of turbine-generator.)

0 10 20 30 40 50 60 70 80 90 100

PER CENT TOTAL HOURS OF OUTAGE

Inspection	2.72%
Boiler — Superheater — Reheater — Economizer — Desuperheater — Air Heater — Fuel Burning Equipment	0.95%
Auxiliary Equipment — Valves — Fans — Soot Blower — Miscellaneous	0.55%
TOTAL	4.22%

PAPER MILL EQUIPMENT; PULVERIZERS; FLASH DRYING SYSTEMS; PRESSURE VESSELS; SOIL PIPE

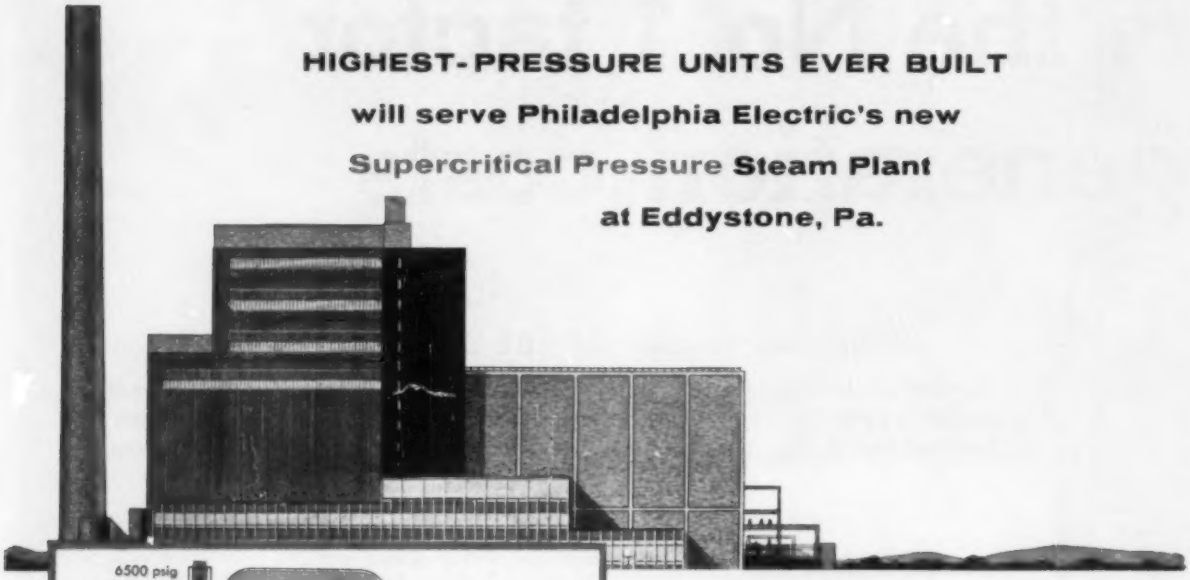
6500 psig
BOILER-FEED PUMPS

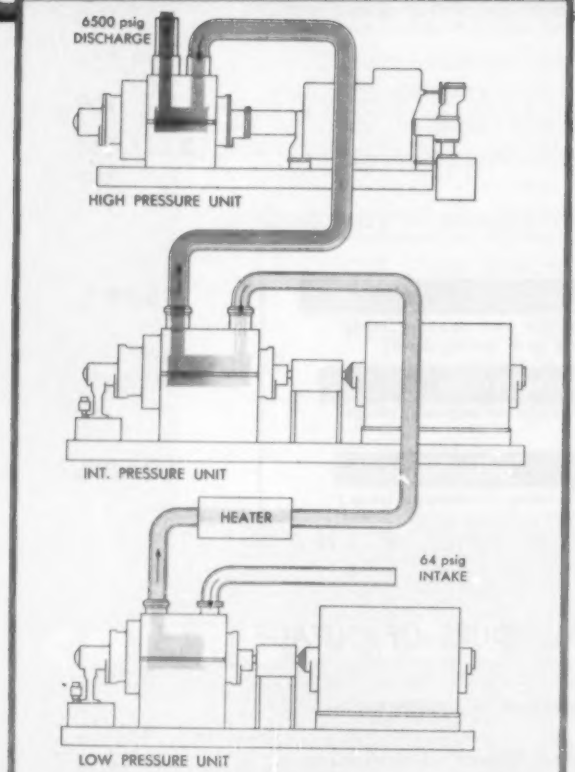
HIGHEST-PRESSURE UNITS EVER BUILT

will serve Philadelphia Electric's new

Supercritical Pressure Steam Plant

at Eddystone, Pa.





Feed water at approximately 6500 psig will be provided by six CHTA pumps, operating as two half-capacity pumping units. Each pumping unit will consist of 3 pumps in series as shown above.

SCHEDULED to go on the line in 1959, Philadelphia Electric Company's 325,000 kw Eddystone Station will operate at a higher steam temperature and pressure than any installation thus far announced. Using supercritical pressure and two reheat stages, it will require less fuel per kw-hr than the most efficient power station now in operation.

The steam generator will be served by six Ingersoll-Rand double-case pumps. To provide the required pressure and capacity they will be arranged as two half-capacity pumping units each consisting of three pumps in series. The suction pressure will be 64 psig and the discharge approximately 6500 psig. The final discharge temperature is 575°F. Featuring Ingersoll-Rand's proven *Unit-Type Rotor Assembly*, these pumps will be the highest-pressure boiler feeders ever built. Special stuffing box designs will be used to control leakage at this supercritical pressure.

The selection of I-R pumps for this historic installation reflects the confidence of Philadelphia Electric Company in Ingersoll-Rand's ability to design and build equipment for pressures and temperatures never before encountered in boiler-feed service.

Whatever your boiler-feed requirements, they can be met to advantage with Ingersoll-Rand centrifugal pumps of proved dependability and economy.

Ingersoll-Rand

11 Broadway, New York 4, N. Y.

10-465

COMPRESSORS • AIR TOOLS • ROCK DRILLS • TURBO BLOWERS • CONDENSERS • CENTRIFUGAL PUMPS • DIESEL AND GAS ENGINES

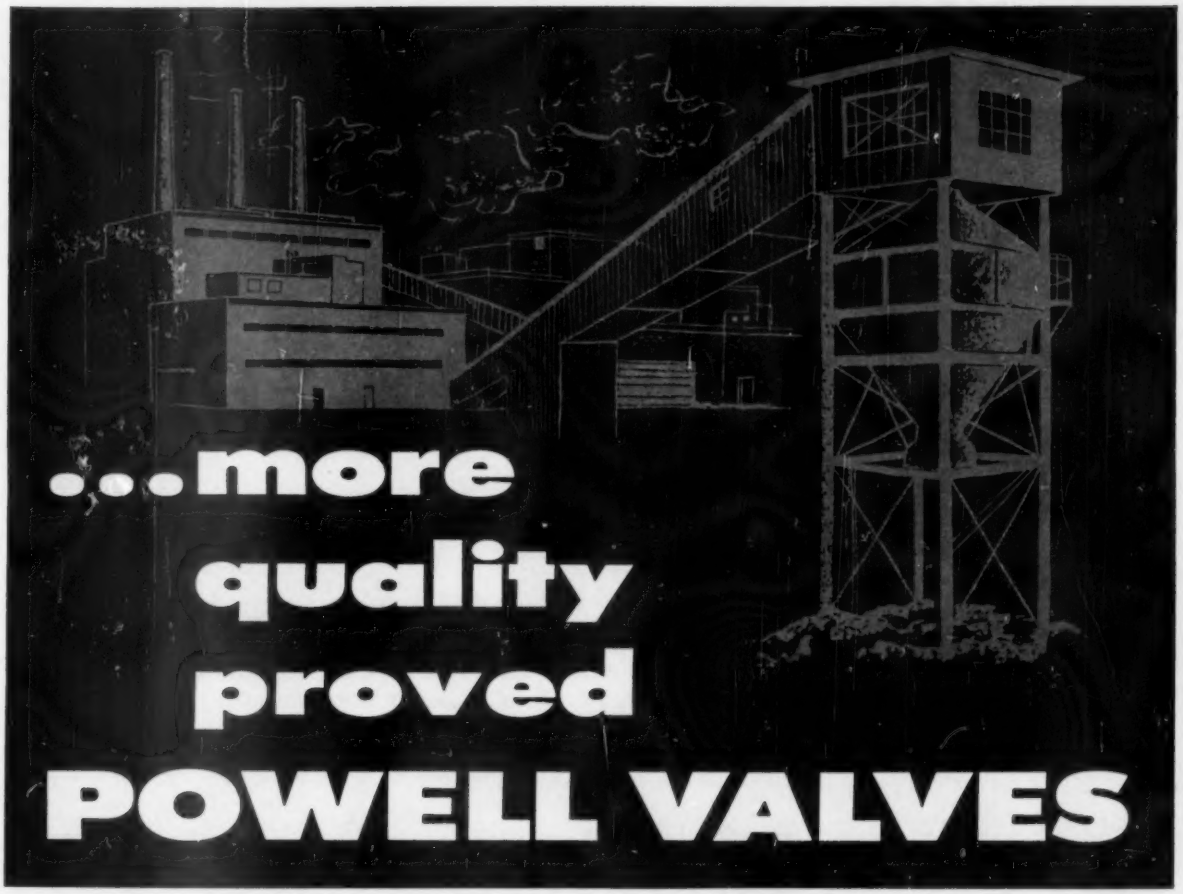


FIG. 9003 W.E.—900-Pound Steel Gate Valve, Bolted Flanged Yoke, Outside Screw, Rising Stem.

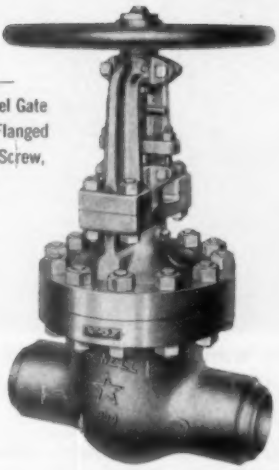
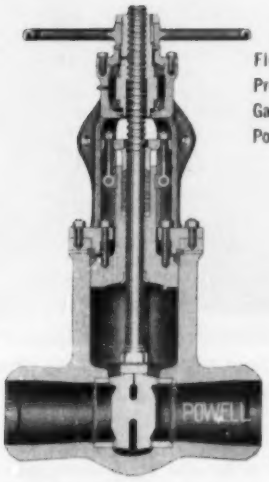


FIG. 375—Bronze Gate Valve for 200 Pounds W.S.P. Inside Screw Rising Stem.

FIG. 11303 (Sec.)—Pressure Seal Steel Gate Valve, 1500 Pounds. Welded Ends.

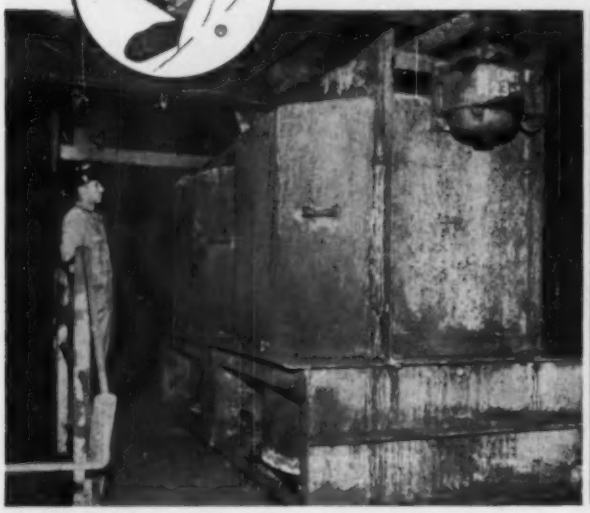


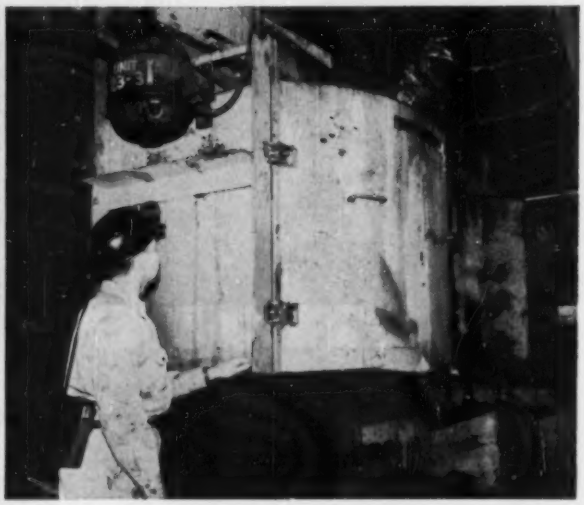
Designed for long life, designed for dependable service

Consult your Powell Valve distributor for all the facts about quality proved bronze, iron, steel and corrosion-resistant valves. For every flow problem . . . there is a Powell Valve to solve it.

THE WM. POWELL COMPANY, CINCINNATI 22, OHIO . . . 111th YEAR

WHY CHESSIE'S RAILWAY IS FIRST IN COAL





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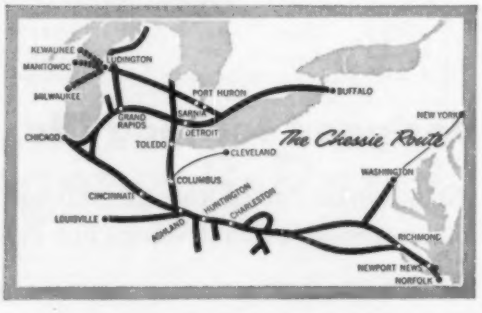

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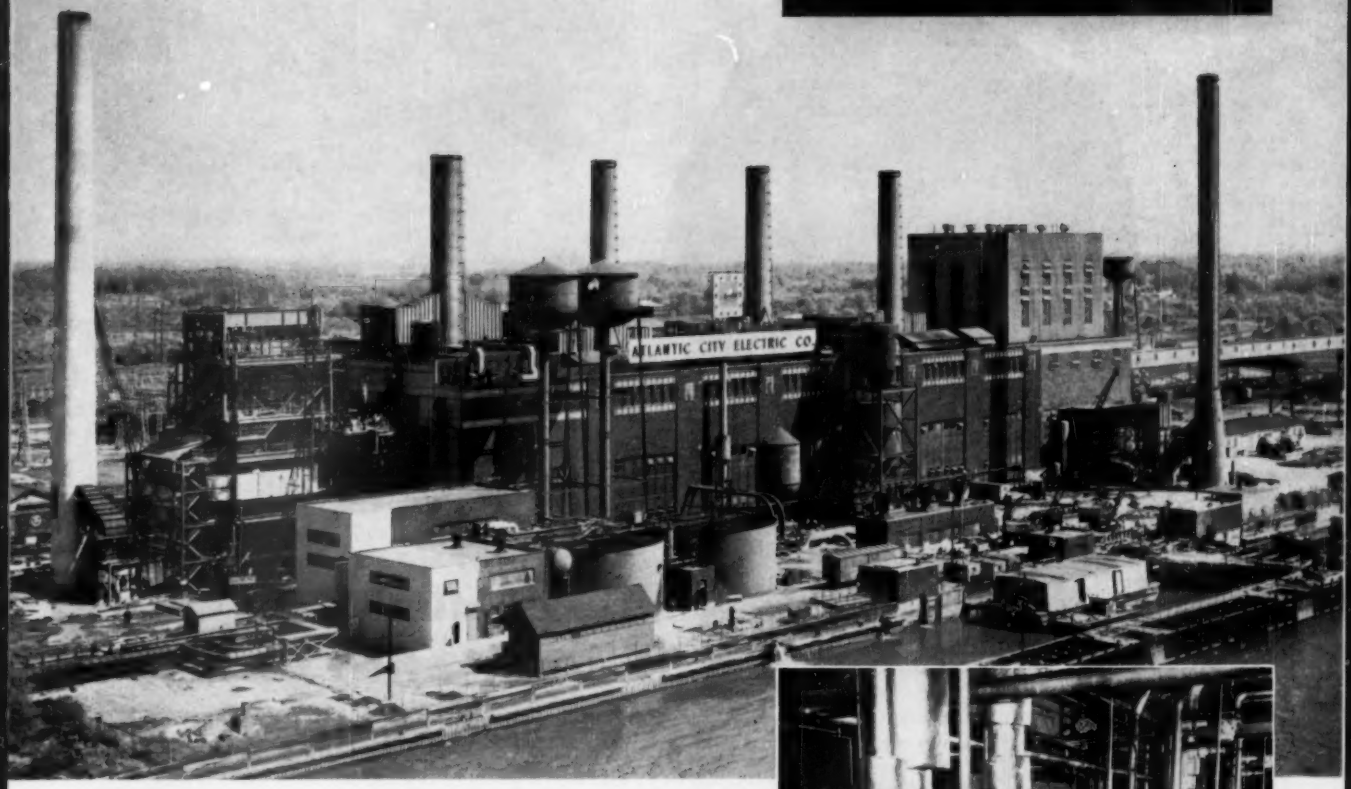

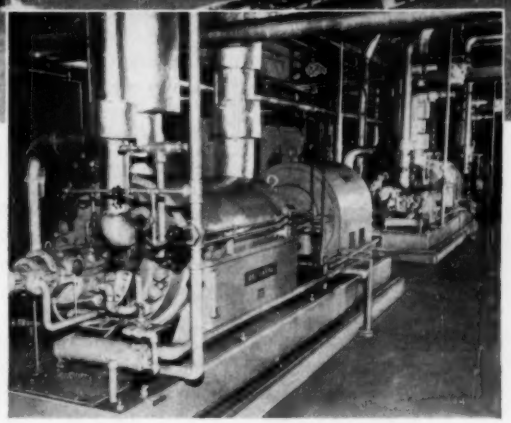

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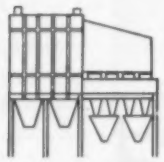

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Editorial

Interlocking Roles of Lawyers and Engineers

At times it appears that lawyers and engineers share little in common except the ability to engage in controversy. This separation of interests is understandable in terms of the basic disciplines that underlie the two professions. Law is one of the social sciences and is concerned primarily with the interrelationships of men and with the many types of social, business and governmental institutions that men have created. Precedents are often used as a guide to legal thinking and action. By contrast, engineering is primarily concerned with applications of the natural sciences. The engineer is rarely interested in precedents, for his thinking is oriented more toward the future possibilities of whatever project he is engaged in.

Despite these differences in basic disciplines and modes of thought, lawyers and engineers actually do share much in common in contemporary society. Engineering applications cannot be made in a social and economic vacuum. Lawyers practice in a society that is greatly affected and changed by technological developments. Substantiation of the truth of these statements is found in two addresses made on May 20 at separate meetings in Washington, D.C.

Speaking before the Society of American Military Engineers, Major General E. C. Itschner, Chief of Army Engineers, stated that engineers must have more authority to control the nation's development and should be held accountable for the social as well as the economic and technical justification of their work. He added that if engineers do not take the lead, some one else will, possibly some one not as qualified as engineers to appraise the far-reaching implications of interlocking development programs.

On the same evening the president of the American Bar Association, David F. Maxwell of Philadelphia, told a group at the American University Law School that atoms and automation are going to make things tougher—as well as easier—for everyone, especially lawyers. He added that the challenges that confront lawyers require more than a commonplace extension of old principles to new situations, or of old law to new cases. Technological developments, including the civilian use of atomic power, may create legal problems of a novelty and complexity that can but vaguely be surmised. It is not certain that the traditions and techniques that law has built up will be adequate for this challenge. Even so, according to Mr. Maxwell, in the final analysis the solution of the myriad problems is not found in the new technology but in the character and values of those who will be applying this technology.

These two addresses point up the limitations of stereotyped concepts of lawyers and engineers. Lawyers do more than file briefs and make impassioned pleas at legal hearings. Engineers have duties and responsibilities far beyond pushing a slide rule or observing an instrument in a laboratory. Their interlocking roles are found in a free society that can neither do without laws nor turn back the clock on technological progress.

The growing popularity of servo systems in the control of power plant functions—from the combustion cycle to supervision of the 'finished product'—has determined the context of this article, the first of two.

This, Part I, has been developed as a refresher for the engineer and as an introduction to servos for the less familiar in the field of combustion.

The Primary Approach To Servo-

By JOHN S. TYNDALL

Elec. Eng.

WITH automatic recording and controlling instruments, the power plant can achieve more efficient and economical generation of electric power and process steam.

In all the multitudes of control systems and their singular applications, servomechanisms are a class unto themselves, they are a branch of automatic regulators that perform the basic function of keeping a *regulated* quantity matched to a *reference* quantity. Four important characteristics usually required of this type of control are: (1) fast response, (2) high accuracy, (3) unattended control, and (4) remote operation.

A servomechanism consists of three basic elements: (1) an error-detecting device, (2) an amplifier, and (3) an error-correcting device. Each element serves a functional purpose in matching the regulated quantity to the reference quantity. The error-detecting device determines when the regulated quantity is different from the reference quantity. It then sends out an error signal to the amplifier which in turn supplies power to the error-correcting device. With this power, the error-correcting device changes the regulated quantity so that it matches the reference quantity. The closed loop in Fig. 2 comprising the error-detecting device, the amplifier, the error-correcting device, and the regulated quantity is characteristic of all servomechanisms.

Reference And Regulated Quantity

Any quantity, e.g., voltage, speed, temperature, draft, position, direction, torque, can be regulated. Any quantity can also be used as a reference quantity. The reference quantity need not have the same units as the regulated one provided the proper error-detecting device is employed.

Error-Detecting Device

The error-detecting device shown in block form, Fig. 2, measures both the reference quantity and the regulated quantity, as indicated by A and B, and detects when they are not similar. When they are not similar, an error signal, represented by e, is produced. The measuring units within the error-detecting device must be the same for both reference and regulated quantities so that their difference e may be obtained.

The Amplifier

The amplifier is merely a means of using the low power signal e from the error-detecting circuit, amplifying it, and then applying it as a load, L, to rectify the error. The correction steps are accomplished by the error-correcting device.[1] Industrial and power plant equipment such as turbine generators, steam boilers are regulated by this method through manipulation of valves, relays, air and liquid flow.

The e-c-d of a servomechanism actually does the work of regulating by producing an output, C, as shown in Fig. 2. The e-d-d and amplifier serve only as a means of properly controlling the e-c-d so as to make the regulated quantity match the reference quantity. Typical e-c-d's include electric motors, solenoids, gas engines, pneumatic and hydraulic instruments, fuel burners and all secondary combustion and power controls.

Applied Control

Applied control is the controlled variation of the reference quantity in order to obtain desired changes in the regulated quantity. A common example of applied control to the reference quantity is the change made in the fuel-feed regulator, thus changing the reference setting of coal or oil flow to boilers. Servomechanisms restore the balance between reference and regulated quantities continuously and automatically to compensate for the effects of applied control and disturbances.

[1] Error-detecting device will henceforth be abbreviated to e-d-d. Error-correcting device will henceforth be abbreviated e-c-d.

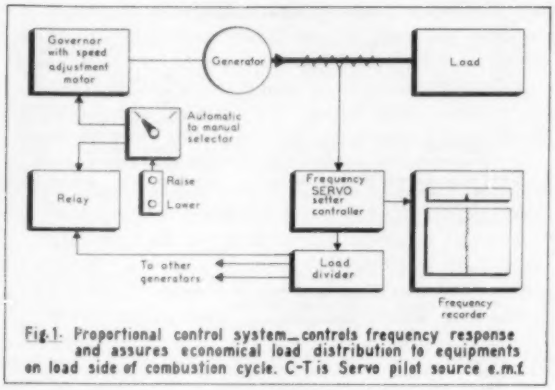


Fig. 1. Proportional control system—controls frequency response and assures economical load distribution to equipments on load side of combustion cycle. C-T is Servo pilot source e.m.f.

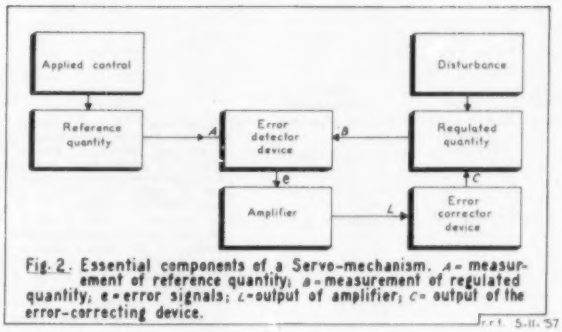


Fig. 2. Essential components of a Servo-mechanism. A = measurement of reference quantity; B = measurement of regulated quantity; e = error signals; L = output of amplifier; C = output of the error-correcting device.

mechanisms in Combustion Control

Forms Of Error-Detecting Device

The e-d-d has many practical forms, and some representative types are given in Table I. Each e-d-d, regardless of whether it is electrical, pneumatic, hydraulic or mechanical, performs three distinct operations: (1) measures the reference quantity A, (2) measures the regulated quantity B, and (3) produces an error signal, e.

Characteristics of an e-d-d that are of great importance to designers, engineers and power plant personnel are (1) energy required to measure reference quantity, (2) accuracy, (3) size, and (4) reliability.

The greatest degree of design ingenuity can be exercised in the selection of an e-d-d, since many special forms and arrangements are possible to decrease operating forces or to increase accuracy and efficiency. For example, the dual synchrosystem will increase accuracy for the control of pulverizer pilots, draft fan control (at controllers) and the positioning of air, water and steam values. When the angular discrepancy is large in any one of these applications, the unity system takes full control and through the amplifier and the e-c-d, brings the angular positions into approximate agreement. At this point the vernier, or high speed, system takes over control of the amplifier (transmitter) and the e-c-d and precisely matches the regulated position (receiver) with the reference position. The vernier system cannot be used alone, since it has as many matching points as its gear ratio is above unity.

The peculiar traits of mechanical, electrical or hydraulic e-d-d's can also be used to advantage. For example, magnetic saturation can be utilized to obtain a particular variation of error voltage with error. Similarly, a non-linear mechanical linkage could be used.

Amplifiers

Some typical amplifiers are shown in Table II. The broad similarity of the amplifiers is apparent, since each contains a "gate" element, G, which controls power flow from the source P to the load L. Each of these gates is a low-power or small force element as compared to the power they control or which they "amplify." For example, the contact (4-8 in Table II) requires only ounce-inches to operate but can control many watts to the load. For high amplification, single amplifiers may be cascaded. The difference in the power available as an error signal and power required to correct the regulated quantity determines the amplification necessary.

Many devices such as contacts, throttles, governors, or valves have their power input determined by the time calculated for optimum operation.

Error-Correcting Devices

Two electrical e-c-d's are shown in Table III. Error-correctors are power devices and include hydraulic motors and pistons, steam and gas prime movers, and fuel burners as well as electric motors and solenoids.

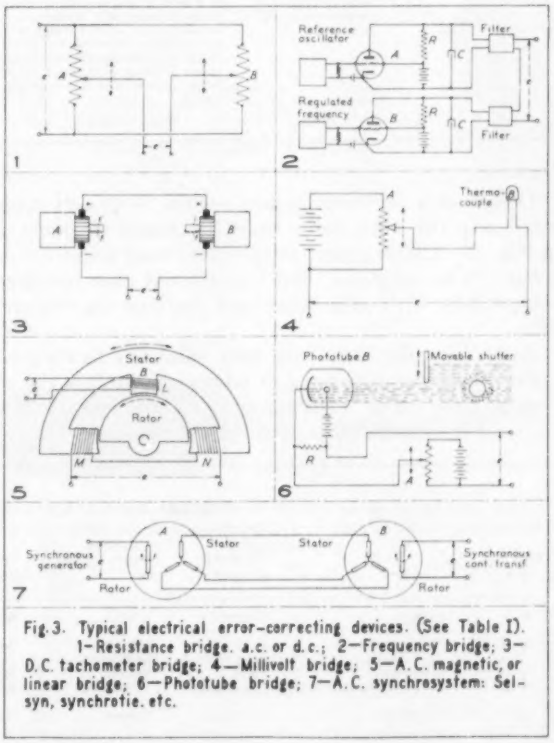


Fig. 3. Typical electrical error-correcting devices. (See Table I). 1—Resistance bridge, a.c. or d.c.; 2—Frequency bridge; 3—D.C. tachometer bridge; 4—Millivolt bridge; 5—A.C. magnetic, or linear bridge; 6—Phototube bridge; 7—A.C. synchrosystem: Selsyn, synchrotie, etc.

TABLE I—TYPICAL ELECTRICAL ERROR—DETECTING DEVICES & THEIR CHARACTERISTICS

Fig. No.	Type	Main Application	Operation	Operating Features	Accuracy Limited By	Features Determining Energy Required to Vary Reference Quantity Measurement A	Amplifier of Table II Frequently Used with This Device
3-1	D-c or a-c resistance bridge	Position control	Error voltage e appears when positions of moving arms of potentiometers A and B are not matched. Power source E is applied across both potentiometers. A measure reference position as voltage and B regulated position as voltage, their difference being e	A and B can be remote. Continuous rotation not possible	Potentiometer winding	Contact arm and bushing friction	2,3,4,5
3-2	Frequency bridge	Frequency control	Error voltage e appears when reference and regulated frequencies differ. Tube channel A produces a filtered saw-tooth wave which gives a d-c voltage inversely proportional to reference frequency. Tube channel B produces a similar voltage as a measure of regulated frequency. Differences of these voltages is e	A and B can be remote. Tubes can be either gas or vacuum. Wide range of frequencies can be covered. Vacuum tubes should be used for high frequencies	Temperature and aging effects on tubes and circuit elements	Tube input impedance	4
3-3	D-c tachometer bridge	Speed control	Error voltage e appears when speeds of tachometers A and B vary. A measured reference speed and B regulated speed as a voltage, their difference being e	A and B can be remote. Top speed limited by commutator	Tachometer accuracy. Commutator resistance	Brush and bearing friction	2,3,4
3-4	Millivolt bridge	Temperature control	Error voltage e appears whenever regulated temperature differs from reference temperature. Regulated temperature is measured as a voltage by thermoelectric effect of two dissimilar metals B. Reference temperature is represented as a voltage from battery-potentiometer source A. Difference in these voltages is e	A and B can be remote. Wide range of temperature can be covered	Ability to detect very low millivolt signals	Contact arm and bushing friction. If electronic voltage source A is used, tube input impedance	2,4
3-5	A-c magnetic bridge	Position control, particularly for gyro pickups where very small forces prevail	Error voltage e appears when relative positions of rotor A and stator B do not match. Rotor A measures reference position magnetically and stator B regulated position magnetically. Voltage e across exciting coil L provides energy. When rotor covers unequal areas of each exposed stator pole (unbalanced magnetic bridge), pickup coils M and N have unequal voltages induced. Voltage difference is e	Limited rotation. Air gap usually small	Machining tolerance, magnetic fringing, voltage-phase shift	Load taken from e. Bearing friction	2,4
3-6	Phototube bridge	Position control by intercepting a light beam	Error voltage appears (e) when movable shutter is in other than desired position. Light reaching phototube B measures shutter position. This light is measured as a voltage by the phototube current variations. A reference position of shutter is represented by battery-potentiometer voltage. Difference of these voltages is e	A and B can be remote. Glass surfaces thru which light travels must be kept clean	Continued accuracy of light source and phototube	Contact arm and bushing friction. If electronic voltage source A is used, tube input impedance	2,4
3-7	A-c synchro-system	Position control where continuous rotation is required as well as torque	Error voltage e appears whenever relative positions of rotors of synchrogenerator A is and synchro-control transformer B are not matched. Reference position is measured by A as a magnetic flux pattern which is transmitted to the receiver B through interconnected stator windings. If rotor of B is not exactly 90 deg from transmitted flux pattern, e is produced	Unlimited rotation. Synchro-generator and "receiver" can be remote	Machining tolerance, accuracy of winding distribution	Distributed or non-distributed winding of control transformer rotor. Load taken from e. Bearing and slip-ring friction	2,4

Design

Design of a servomechanism system is usually separated into the same three basic functional elements as in Fig. 2. The designer (or specifier) must select (1) an e-d-d, (2) an amplifier, and (3) an e-c-d that functions compatibily with each other and perform the required job.

Aside from the usual cost and reliability factors, accuracy and operating force or power, determines the selection of the e-d-d. The amplifier is chosen on the basis of needed amplification and time-delay introduced—whether deliberate or through uncontrolled inertia. The e-c-d is determined by the regulated quantity and ease of coupling to the selected amplifier.

The Tables I, II, and III are helpful for devising servomechanisms and associated circuits and systems. For example, suppose that it is desired to control the angular position of a chimney damper. With relatively low accuracy, a d-c or a-c resistance bridge (driven by damper linkage) a relay and an electric servo motor could be successfully used. Higher accuracy could be obtained by applying an a-c synchrosystem with an electronic

TABLE II—TYPICAL ELECTRICAL AMPLIFIERS AND THEIR CHARACTERISTICS

Fig. No.	Type	"Gate" Element	Approx. Input Units	Approx. Output Units	Approx. Power-Amplification Factor	Devices Represented by Load L	Power Control
4-8	Contact	Contact	Oz.	Watts	$1 \times 10^7 \times t$	Relay, motor, Generator, field, impedances, solenoids	On-off
4-9	Relay	Contact	Watts	Watts or kw	1×10^3	Relay, motor, gen. field impedance, solenoid	On-off
4-10	Electronic tube	Grid	Microwatts Milliwatts	Watts	1×10^6	Relay, motor, gen. field imp.	Continuous
4-11	Generator	Field	Watts	Watts or kw	50	Motor impedance	Continuous
4-12	Saturable reactor	D-c coil	Milliwatts	Watts	3×10^2	Generator field impedance	Continuous
4-13	Silverstat	Contacts	Grams	Watts	$1 \times 10^7 \times t$	Generator field impedance	Stepped

tube, a generator and an electric motor. However, this particular application would not require an involved system. Each of these is a complete servomechanism, and each has its proper place in meeting desired performance requirements. The components can be selected from the Table and cross-referenced pictorially in Figs. 3 (cuts 1 through 7) and Figs. 4 and 5 (Cuts 8 through 14b). The power of the e-c-d is determined by the rate at which it is desired to vary the regulated quantity—and whether in incremental steps or "stepless." The rate of varying the regulated quantity also determines the transient errors and to a great extent the tendency of the entire servomechanism system to "hunt" or oscillate.

Hunting, or self-induced oscillation of the regulated quantity without change in the reference quantity, is a problem that complicates all quick-response, high-accuracy servomechanisms. Any closed-loop system, such as shown in Fig. 2, where the output feeds back into the input has a tendency to oscillate. However, the inherent damping in the simpler servomechanisms is usually great enough to overcome this tendency, and the system is stable. Where accuracy and response requirements are not too severe, a servomechanism of the self-damped type will perform satisfactorily. To meet the more exacting requirements, special anti-hunt circuits are incorporated to give increased damping.

Fig. 6 and Fig. 7 are typical of the many types of a-c and d-c servomotor units being used today in industry and utilities.

Experience has proved that automatic control improves station operation by holding steam, water, fuel, voltage, current, frequency, more consistently constant. When properly applied, control does not produce excessive wear on equipment such as valves, governors, slides, regulators, nor does it produce excessive loads on boilers and fuel injector systems. In fact, experience has shown an improvement in overall efficiency.

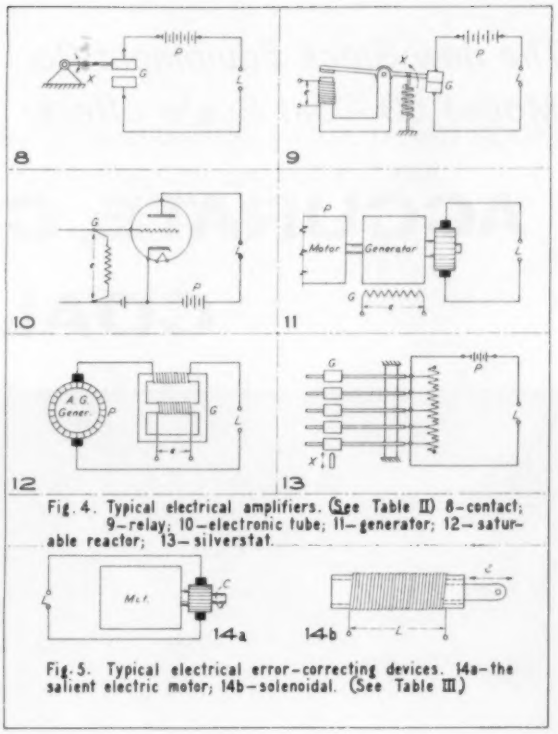


Fig. 4. Typical electrical amplifiers. (See Table II) 8—contact; 9—relay; 10—electronic tube; 11—generator; 12—saturable reactor; 13—silverstat.

Fig. 5. Typical electrical error-correcting devices. 14a—the salient electric motor; 14b—solenoidal. (See Table III)

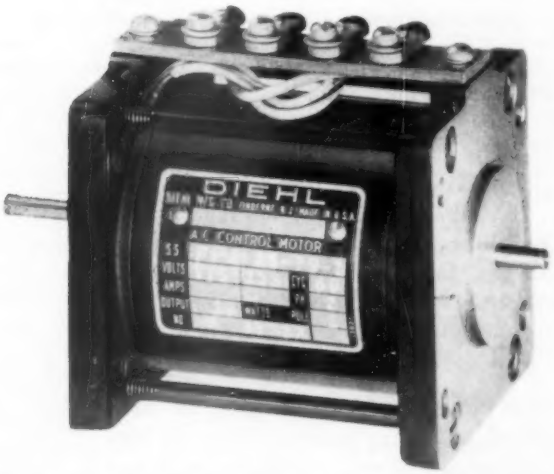


Fig. 6.—A high-accelerating a-c low inertia servomotor typical of those used in combustion control and register panels

TABLE III—TYPICAL ELECTRICAL ERROR-CORRECTING DEVICES

DWG. No.	Type	Input Energy	Output Energy	Approx. Output Power Range
5-14-a	Electric motor	Electric	Mech. Rotation	1×10^{-3} to 4×10^{1} hp
5-14-b	Solenoid	Electric	Mech. Translation	1×10^{-3} to 15 hp

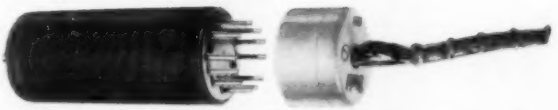


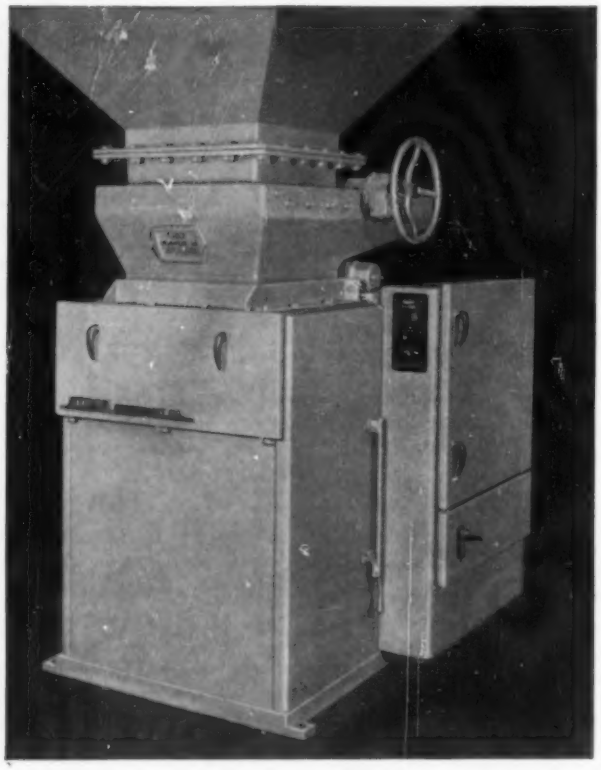
Fig. 7.—Precision servomechanism resolvers of the above type are often used in calculation of combustion and power networks

Editor's Note:

This series by Mr. Tyndall is presently planned to run through our November issue and total five parts in all. Certain of the theory will be presented as well as a review of application.

The new Stock Equipment Co. Model 50 Coal Scale offers:

ACCURATE, CONTINUOUS COAL WEIGHTS... WITHOUT FAIL!



with little or no attention

Day-in and day-out operation, twenty-four hours on end without interruption, is a necessity for modern central stations and industrial power plants. The demand is for equipment to handle higher tonnages with less manpower—and Stock Equipment Co. is meeting that demand with a constructive design program that keeps its entire line up-to-date.

For example: The new Model 50 Coal Scale handles higher tonnages easily with its 500# stainless steel weigh hopper, extra wide feed belt and unrestricted flow of coal 24" wide straight through the scale. Anti-friction bearings are used throughout. Even the feed belt is carried on closely spaced idlers with anti-friction bearings carefully arranged for pressure lubrication from one point on each side.

Seventeen years of designing scales exclusively for power plant use make a S-E-Co. Scale the answer to your coal weighing problem. Write for help with your particular layout of Bunker to Pulverizer or Bunker to Stoker equipment to the address below.

STOCK Equipment Company

745-C HANNA BLDG. CLEVELAND 15, OHIO

Sulfur in fuel oils causes a considerable rise in the dewpoint of the flue gases. To avoid corrosion of heat-exchanger surfaces, it is the general practice to maintain these at temperatures above the acid dewpoint, with a consequent loss of thermal efficiency over that obtainable in the absence of sulfur. The injection of ammonia into the combustion gases, the authors state, appears to be an efficient and economical method of eliminating the acid dewpoint, and of reducing the corrosion of exposed steel surfaces to a negligible level.

By L. K. RENDLE[1] and R. D. WILSDON[1]
British Petroleum Co., Ltd.

The Prevention of Acid Condensation in Oil-fired Boilers*

IN recent years increasing attention has been drawn to the important problem of low-temperature corrosion in the economizers and air-heaters of boilers, and much valuable work has been published on this subject.

The basic cause of the corrosion is well known, although the precise mechanisms of the reactions taking place are still controversial. Briefly, the bulk of the sulfur compounds in the fuel is oxidized to SO_2 on combustion, but a small proportion of this is further oxidized to SO_3. This may occur in the combustion zone, as the result of reaction with short-lived, highly reactive oxygen atoms present in the immediate vicinity of the flame, or by a catalytic oxidation process initiated by ferric oxide or ferric sulfate at high temperatures. Although the SO_3 is present in the flue gases in very low concentrations (about 0.002 to 0.005 per cent by volume in the dry flue gases) it causes a rise in the dewpoint from a water dewpoint of about 40-to-45 C to about 140 C (depending on the excess air used in combustion, on the flame temperature, and on the sulfur content of the fuel); sulfuric acid may condense on any surfaces at or below the dew-point temperature. To prevent condensation and subsequent corrosion on economizer and air-heater surfaces, it has been the practice to maintain these at temperatures well above the acid dewpoint of the flue-gases, thus protecting the heat-exchange surfaces at the expense of a considerable reduction of the overall thermal efficiency. A knowledge of the acid dewpoint/fuel sulfur content relationship is thus desirable to enable the acid dewpoint of the flue gases to be predicted for a fuel oil of known sulfur content.

The method of avoiding corrosion by maintaining the cooled surfaces above the acid dewpoint achieves its object at the expense of reduced efficiency, but does not strike at the root of the problem, which is the presence of SO_3 in the flue gases. In the past, many methods of removing this material have been tried but none has been entirely successful, except at prohibitive cost.

The work described in the paper began as a laboratory investigation into the effect that the sulfur content of fuel oils had on the dewpoints of flue gases and continued as a search for an economic method of removing the SO_3 in a harmless form.

Experimental Apparatus and Techniques

The furnace was designed so that no steel surfaces were exposed to the flue gases at temperatures greater than about 250 C, to minimize the catalytic oxidation of the SO_2. A plan of the basic arrangement is shown in Fig. 1. Approximately two-thirds of the flue gases from

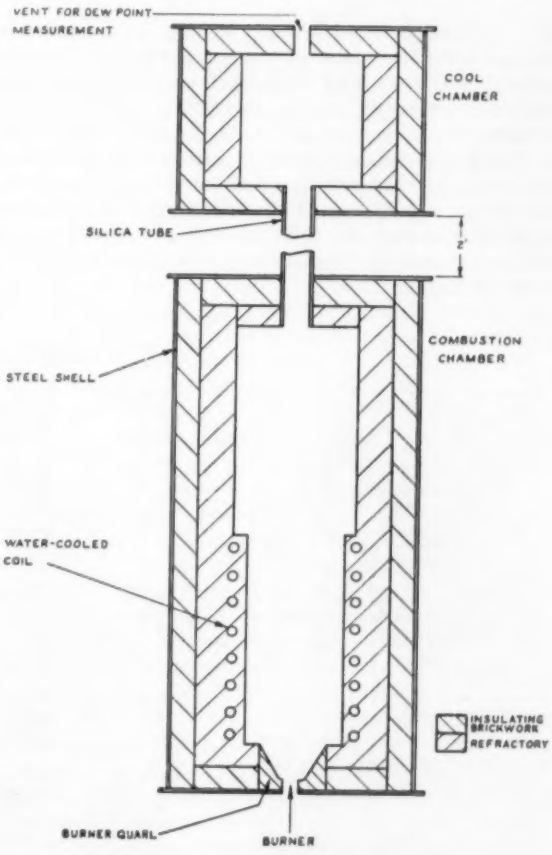


Fig. 1.—Plan of furnace

* Reprinted from the Journal of the Institute of Fuel, 18 Devonshire St., Portland Place, London, Sept. 1956.
[1] Research Station, Sunbury-on-Thames.
[2] Numbers in parentheses refer to Bibliography at the end of the article.

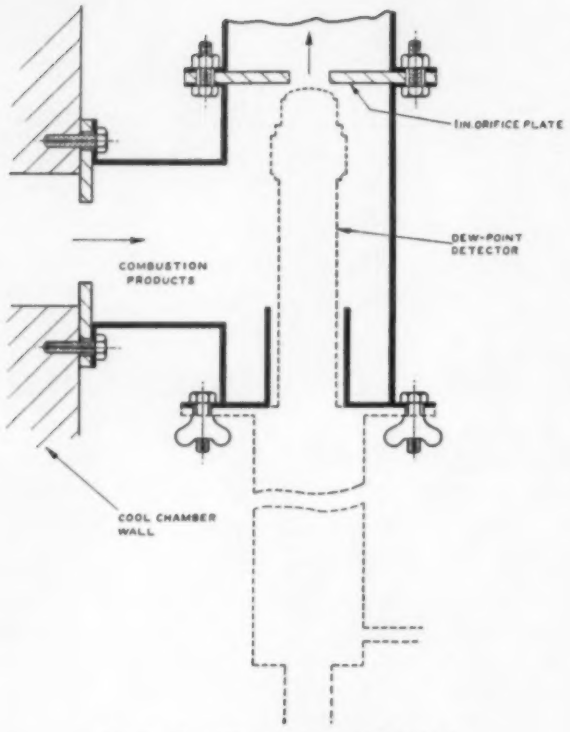


Fig. 2.—Location of dew-point detector

the combustion chamber are vented to atmosphere through a vertical stack, the remainder passing through a silica tube to a "cool" chamber; an extraction fan is used to withdraw the flue gases from the "cool" chamber. A water-cooled coil, embedded in the refractory in the combustion chamber, is used to absorb some of the unwanted heat. A "Y"-type medium-pressure, air-atomized burner was used, capable of burning 6 to 10 lbs per hr of residual fuel oil. The ducting at the cold end of the furnace and the location of the dewpoint detector is shown in Fig. 2.

The dew-point measurement method employed is basically identical to that developed by (British Coal Utilization Research Assn.) BCURA (1, 2)[2] and depends upon the measurement of the rate of increase of electrical conductance of a condensed acid film at different temperatures. The acid film is formed on the plane end surface of a cooled Pyrex glass thimble, which is exposed to the flue gases. The rate of increase of conductance is plotted as a function of temperature, and from this curve is read the lowest temperature corresponding to zero rate of increase of conductance. This temperature is taken as the dewpoint.

A corrosion probe (3) of the type used by BCURA, was used to measure corrosion rates. The probe consists of a hemispherical mild-steel cap into which a thermocouple is brazed. The cap, which can be cooled by an air blast impinging on its inner surface, is mounted at the end of a steel tube.

The mild-steel hemisphere, after being polished with fine emery, is exposed to the flue gases, and its temperature is maintained at the required level by adjusting the cooling air. After an exposure period of one hour, the corrosion products on the cap are washed with boiling distilled water into a flask, and the washings are analyzed quantitatively for iron and sulfate.

The chemical method employed was based on that developed by BCURA (4, 5) with a few minor modifications. Briefly, the flue gases are sampled through a heated silica tube and are absorbed in 80 per cent by volume isopropyl alcohol in water, which prevents further oxidation of the SO_2. The SO_3 is determined photo-turbidometrically after precipitation as barium sulfate, and the SO_2 by an iodine/thiosulfate titration.

The Dependence of Dewpoint on Fuel Sulfur Content

A range of fuels was chosen for this work with sulfur contents varying from 0.09 to 4.36 per cent by weight the inspection data for these oils (Nos. I to VII) are given in Table 1.

To broaden the scope of the tests, the sulfur contents of four of these oils were increased by adding carbon disulfide in varying amounts. The sulfur contents of

TABLE I.—INSPECTION DATA ON OILS USED

Oil	I	II	III	IV	V	VI	VII
Specific gravity 60°/60° F	0.9353	0.9325	0.951	0.9915	0.924	0.836	0.935
Specific gravity 140°/60° F	0.9065	0.9045	...	...	...	...	0.906
Flash point, °F	295.0	174.0	255.0	235.0	...	...	166.0
Calorific value (calc.), Btu/lb	18,760	18,520	18,590	17,950	18,680	...	18,470
Kinematic viscosity at 100° F, cs.	...	...	...	...	...	...	100.0
Kinematic viscosity at 140° F, cs.	57.04	42.10	190.5	174.0	4.27	...	37.56
Kinematic viscosity at 170° F, cs.	29.36	23.35	82.92	78.9	3.05	...	21.14
Kinematic viscosity at 210° F, cs.	14.59	12.34	35.11	32.8	2.11	...	11.39
Viscosity Redwood I at 100° F (calc), sec	1007	453	3140	3120	45	...	406
Pour point, ° F	85.0	0	15.0	30.0	4.5	...	45.0
Asphaltenes, per cent wt	0.67	0.96	2.04	6.15	Nil	...	1.83
Soft asphalt, per cent wt	4.5	7.7	10.0	...	...	...	5.7
Total acidity, mg KOH/g	0.25	0.2	1.18	0.34	...	...	0.25
Mineral acidity, mg KOH/g	Nil	Nil	Nil	...	...	...	Nil
Water content, per cent vol	Nil	Trace	0.2	Nil	Trace	...	Trace
Water + sediment, per cent vol	0.15	0.05	0.3	...	...	...	0.2
Sediment by extraction, per cent wt	0.030	0.010	0.06	...	...	...	0.024
Wax content, per cent wt	13.3	8.3	4.8	8.8	13.1	...	11.5
Melting-point of wax, ° F	131	138	138	133	105	...	135
Nitrogen, per cent wt	0.235	0.15	0.28	0.26	0.022	...	0.165
Ultimate analysis							
Carbon, per cent wt	86.2	84.6	86.34	85.28	86.0	...	85.1
Hydrogen, per cent wt	12.2	12.0	12.0	10.36	11.3	...	11.9
Sulfur, per cent wt	1.6	3.4	1.66	4.36	2.7	0.09	3.16
Ash, per cent wt	0.091	0.034	0.105	0.0285	0.004	...	0.033
Composition of ash; per cent wt on oil							
Vanadium as V_2O_5	0.0127	0.0170	0.0130	0.0093		...	...
Nickel as NiO	0.0018	0.0012	0.0040	0.0013	...	...	...
Iron as Fe_2O_3	0.0258	0.0071	0.0015	0.0025	...	...	...
Calcium as CaO	0.0002	0.0001	0.0045	0.0001	...	...	...
Aluminium as Al_2O_3	0.0002	0.0001	0.0004	0.0001	...	...	...
Sodium as Na_2O	0.0072	0.0014	0.0176	0.0054	...	...	...
Silicon as SiO_2	0.0010	0.0009	0.0040	0.0002	...	...	...
Sulfur as SO_3	0.0420	0.0127	0.0344	0.0072	...	...	...

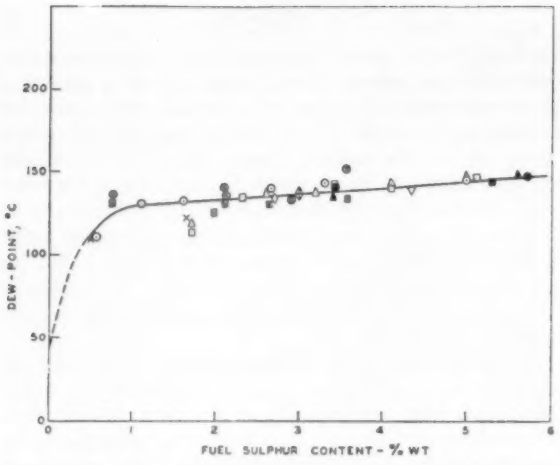


Fig. 3.—Variation of measured dewpoints of fuel combustion gases with sulfur content of fuel. All data refer to 25 per cent excess air for combustion

- ○ Oil I + carbon disulfide or gas oil.
- ● Oil I + petroleum disulfides.
- ⊡ Oil II + carbon disulfide or gas oil.
- ■ Oil II + petroleum disulfides.
- △ Oil III + carbon disulfide.
- ▲ Oil III + petroleum disulfides.
- ◬ Oil IV.
- ◈ Oil V.
- × Oil VI + carbon disulfide.
- ⊠ Corbett's data.
- ⊗ Flint's data.
- ✦ Taylor and Lewis' data.

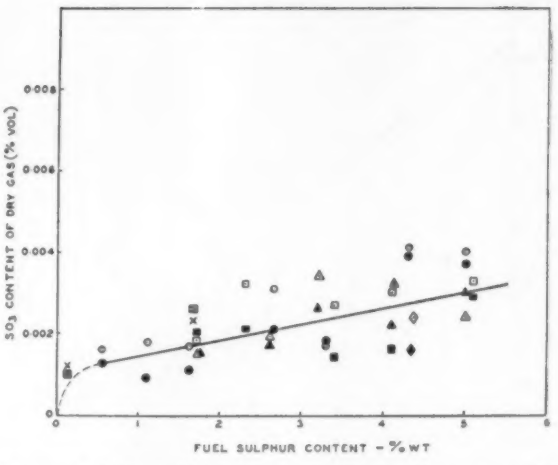


Fig. 4—Variation of SO_3 content of combustion gases with sulfur content of fuel. Gases contain 10 per cent by volume water vapor

Gas samples from combustion chamber:

- ○ Oil I + carbon disulfide or gas oil.
- ⊡ Oil II + carbon disulfide or gas oil.
- △ Oil III + carbon disulfide.
- ◈ Oil IV.
- × Oil VI + carbon disulfide

Gas samples from cool chamber:

- ● Oil I + carbon disulfide or gas oil.
- ■ Oil II + carbon disulfide or gas oil.
- ▲ Oil III + carbon disulfide.
- ✦ Oil IV.
- ⊠ Oil VI + carbon disulfide.

two of the oils were also reduced by dilution with a low-sulfur gas oil. Dewpoints were determined on the combustion gases from each of the fuels and blends, and sulfur oxide determinations were made on the majority.

The experimental furnace was run under the following conditions throughout the tests: excess air, 25 per cent; combustion-chamber temperature, 1000 C; "cool" chamber temperature, about 350 C.

A criticism of the method of increasing the sulfur content of some of the oils by adding carbon disulfide was subsequently made on the grounds that the carbon sulfur bonds in carbon disulfide are of a type not found in petroleum compounds. Some experiments were therefore made in which petroleum disulfides were added to the base oils; these blends gave results which were in close agreement with the previous experiments with carbon disulfide, showing that the form in which the sulfur is present in the oil is unimportant. The dewpoint/fuel sulfur content relationship determined is shown in Fig. 3, which also shows results published by Corbett, (6) who used an oil-fired water-tube boiler. Other data shown in Fig. 3 were obtained by Flint and others, (7) and by Taylor and Lewis, (8) using small, oil-fired refractory furnaces.

The data from all these sources can be represented satisfactorily by one curve, which shows that the acid dewpoint increases rapidly at first and the fuel sulfur content increases. The theoretical water dewpoint of the flue gases is about 45 C and a fuel of only one per cent weight sulfur content has an acid dewpoint in the region of 130 C. At higher sulfur contents there is a much more gradual rise in the dewpoint and this is directly proportional to the increase of fuel sulfur content. For fuels of sulfur content from one per cent to 5 per cent by weight, the dewpoint rises by approximately 4 C for each one per cent weight rise in sulfur content. Thus, to bring about an appreciable reduction in the dewpoint by the desulfurization or dilution of high-sulfur fuels, it would be necessary to reduce the sulfur content to below 0.5 per cent by weight.

Fig. 4 shows that there is a progressive increase in the SO_3 content of the combustion products as the fuel sulfur content increases. The SO_3 content increases from 0.001 per cent by volume for low-sulfur gas oil of 0.12 per cent by weight sulfur content to 0.004 per cent by volume for fuel oil of 5 per cent by weight sulfur content, using 25 per cent excess air and at a combustion-chamber temperature of 1000 C.

When the sulfur content of fuels naturally low in sulfur was increased by the addition of 20 per cent by volume of carbon disulfide in gas oil, considerable dilution of the fuel oil by gas oil occurred. This dilution introduced some doubt concerning the possible effects of hydrocarbon type, boiling range or ash constituents on the dewpoints. The published data of Corbett (6) obtained on an industrial water-tube boiler had suggested that the dewpoint was dependent on these properties. This was investigated by using a catalytically cracked heavy cycle oil (Oil No. V, Table 1), which has a different hydrocarbon structure from straight-run residues; the boiling range is also different and the oil contains a negligible quantity of ash. The result of the dewpoint measurement, shown in Fig. 3, indicates that, in this instance, fuel hydrocarbon type, boiling range and ash content have no effect on the acid dewpoint of the combustion gases.

Further information on the effect of the ash constituents of the fuel on the dewpoint may be obtained by com-

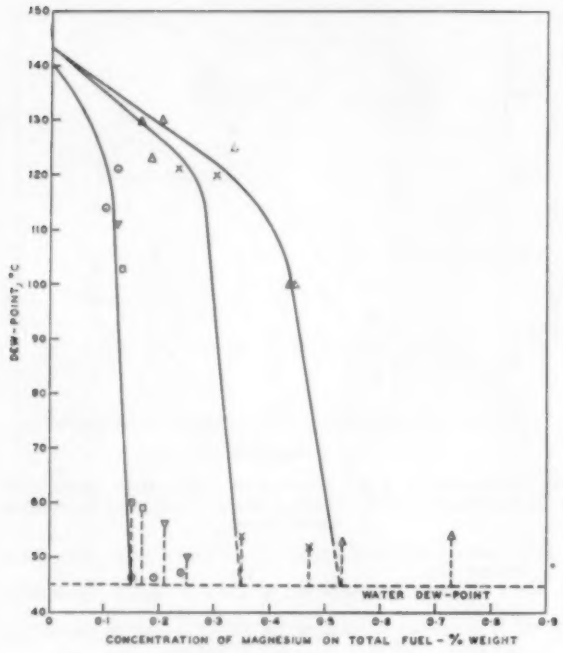


Fig. 5—Variation of dewpoint with concentration of magnesium for magnesium naphthenate, magnesium soaps and magnesium oxide (light)

⊙ Magnesium naphthenate.
× Magnesium oxide (light), injected as gas oil suspension.
△ Magnesium oxide (light), added dry with secondary air.
▽ Magnesium soap, made with blown pork-fat.
⊡ Magnesium soap, made with fatty-acid pitch.

paring the results of dewpoint measurements made on the combustion products from the various residual fuels examined. From the properties of the heavy fuels given in Table 1 it is seen that the ash contents range from 0.029 per cent weight to 0.105 per cent weight. Of the ash constituents present, vanadium which occurs to the extent of 0.009 to 0.017 per cent weight (as V_2O_5) in the basic fuel, is likely to have the greatest influence on the dewpoint. From the data shown in Fig. 3, however, there is no evidence that vanadium or any other ash constituent has any effect on dewpoint. This is in agreement with the work of Taylor and Lewis, (8) who found that addition of 0.45 per cent by weight of vanadium pentoxide (added as vanadium naphthenate) to gas oil had no effect on dewpoint.

Materials for Depressing the Acid Dewpoint

The use of a variety of materials for depressing the acid dewpoint of flue gases has been described in the technical literature of recent years. These materials fall into three main classes, depending on the mechanism by which the SO_3 is removed:

(*a*) Materials which physically adsorb SO_3, such as silica (9) or carbon (10, 11). For efficient adsorption the materials must be introduced in an activated, finely divided form as smokes or dusts, so that a maximum specific surface area is offered to the gases.

(*b*) Materials which combine preferentially with the atomic oxygen present in the flame zone or which promote recombination of the oxygen atoms with consequent inhibition of the reaction:

$$SO_2 + O \rightarrow SO_3 \qquad (1)$$

Some relatively inert materials, such as carbon and silica, may also belong to this group, as it is known that the recombination of atoms is facilitated by the presence of solid surfaces which are capable of absorbing the energy of recombination. Again, the efficiency of the process depends on the available surface area of the solid.

(*c*) Materials which combine with SO_3 chemically to form non-corrosive compounds, which are carried away by the combustion gases: compounds of zinc (7, 12, 13) and magnesium fall into this category. For efficient contacting with the SO_3 a high active surface volume ratio is again necessary.

Materials from each of these classes have been assessed in the experimental furnace, but all of the materials which were successful in eliminating the acid dewpoint belonged to class (*c*). The furnace was run under the following conditions throughout the tests: excess air, 25 per cent; combustion-chamber temperature, 1000 C; "cool"-chamber temperature, about 300 C. The fuels used were Nos. II and VII (Table I).

Silica Powders

Three finely divided silica powders, the average particle sizes of which ranged from 0.015-to one μ, were introduced into the combustion zone by continuously injecting suspensions in gas oil into the fuel-oil feed line to the burner by means of a diesel injection pump. A precipitated aluminum silicate and a fine china clay were also injected in this way.

The maximum depression obtained was 14 C, using a concentration of 0.43 per cent by weight of fuel of the finest silica powder. A commercial ethyl silicate, which

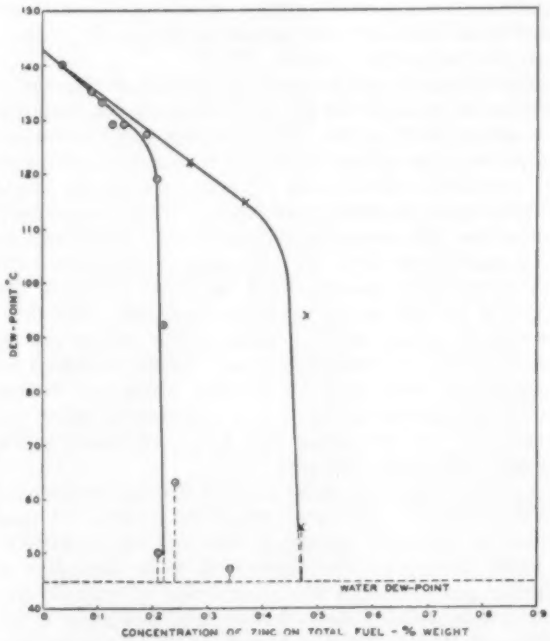


Fig. 6—Variation of dewpoint with concentration of zinc for zinc naphthenate and zinc dust

⊙ Zinc naphthenate. × Zinc dust.

was tested similarly, gave a depression of 12 C at a concentration of 0.46 per cent by weight (expressed as SiO_2) on fuel. At higher concentrations of these materials the flame stability was reduced and deposits, which interfered with conductance readings, built up on the dewpoint element; these factors limited the additive concentrations to the quoted levels.

Effect of Carbon

A considerable amount of work has been reported on the effects of carbon smokes on the dewpoints and corrosive properties of flue gases (10, 11). Some of the statements made in the literature on this subject are conflicting, but the general conclusions are that carbon smokes introduced from auxiliary sources can be beneficial at temperatures below the dewpoint, whereas smokes produced by operating furnaces with low excess-air ratios may promote corrosion (14).

In the present work, two grades of carbon black were tested by injecting suspensions in gas oils into the fuel-oil feed line. Additions were also made at the rear of the combustion chamber to shorten the residence time in the flame zone and so to prevent complete oxidation. No significant change in the dewpoint was observed at concentrations up to 0.5 per cent by weight of carbon on oil feed; at higher carbon concentrations conducting deposits were formed on the probe element, which prevented dewpoint determinations. The effect of carbon smokes formed by the use of an auxiliary oil spray was also determined (15). Gas oil was sprayed downwards into the combustion chamber at a point approximately one foot from the inner rear surface at concentrations ranging from 3.3 to 11.3 per cent by weight on the total fuel input; the gas oil burnt with a smoky flame, but no significant depression of the dewpoint was obtained by this method.

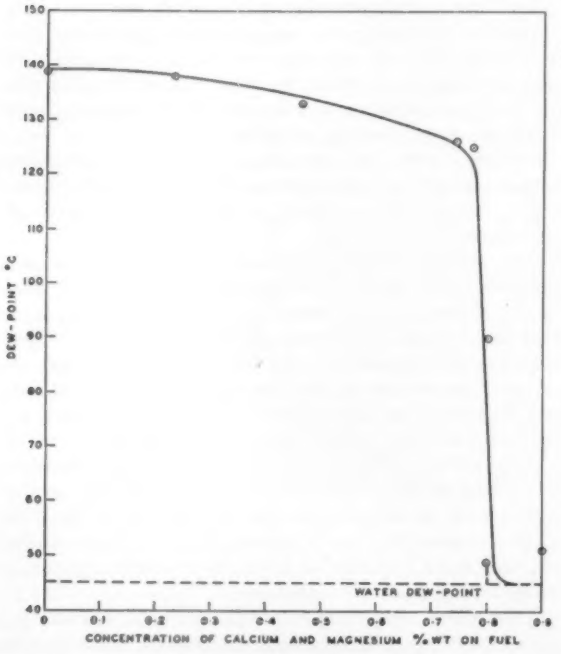


Fig. 7—Variation of dewpoint with concentration of calcium and magnesium for dolomite

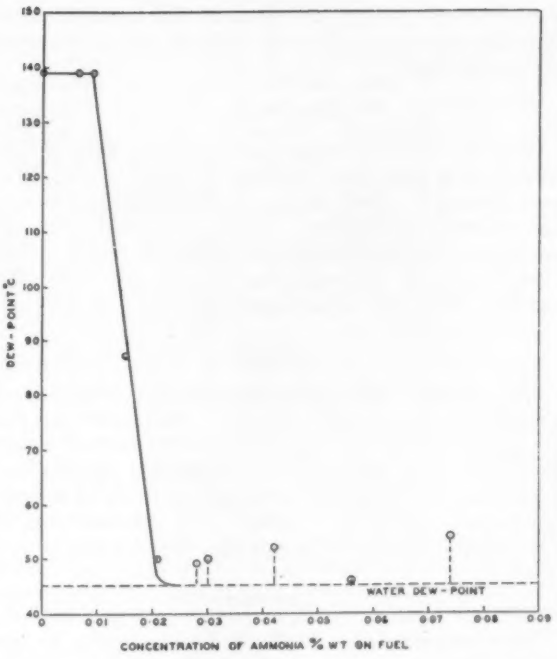


Fig. 8—Variation of dewpoint with concentration of ammonia

Nitrogenous Materials

The theory (16) has been put forward that nitric oxide introduced into a furnace flame would compete with the SO_2 for the available atomic oxygen, thus inhibiting the formation of SO_3; the higher oxides of nitrogen formed would then pass harmlessly through the low-temperature end of the boiler without condensation. It can be shown theoretically that no nitric acid dewpoint exists under these conditions.

The materials selected for testing were tars, from the shale-oil and coal-gas industries, containing pyridine and other organic nitrogen compounds; no significant dewpoint depressions were produced, however, at concentrations of 2.4 to 2.7 per cent by weight of these materials on the total oil feed.

Oil-soluble Metallic Soaps

Dewpoint determinations were made using various concentrations of magnesium and zinc naphthenates, dissolved in gas oil, and injected into the fuel-oil supply to the burner. Two magnesium soaps, prepared from magnesium oxide (light) by dissolving it in a blown pork-fat and a fatty acid pitch were also tested in the same way. Water dewpoints were obtained with all these materials, and Figs. 5 and 6 show the variation in dewpoint with the concentration of the metallic elements.

Magnesium Oxide

The effect on the dewpoint of combustion gases of introducing magnesium oxide into the furnace in the form of the finely-divided light oxide was studied, both by injecting a suspension in gas oil into the fuel-oil supply to the burner, and also by blowing the dry oxide into the secondary-air supply. The acid dewpoint was eliminated by both methods; curves of dewpoint vs.

additive concentration are given in Fig. 5, which shows that the injection of the oxide with the fuel is the more efficient method.

Zinc Dust

Powdered zinc of average particle size 4μ was added as a suspension in gas oil to the fuel-oil supply to the burner and produced a finely dispersed smoke of zinc oxide in the combustion chamber. Water dewpoints were obtained by this method but the efficiency was less than that obtained by the use of zinc naphthenate. The dewpoint/additive concentration curve is given in Fig. 6.

Dolomite

This material was used in the form of a finely-ground powder of average particle size 5μ. The powder was suspended in gas oil and injected into the fuel-oil supply line. The acid dewpoint was eliminated by this material, but the efficiency was lower than that of magnesium oxide. A curve of dewpoint vs. concentration of the metallic elements (Ca and Mg) is given in Fig. 7.

Ammonia

The most successful results were obtained by the use of materials which combined directly with the SO_3 in the combustion gases to form non-corrosive products which largely remained suspended in the flue gases and which were vented to atmosphere without excessive condensation or settling. All of the materials already described which eliminated the acid dewpoint were solids which were injected into the flame zone either as suspensions or as solutions in oil. The contacting efficiencies were thus proportional to the available surface areas of the oxides produced on combustion and depended on the state of sub-division of the particles. The concentrations of the additives required to neutralize the SO_3 in the flue gases were in all cases considerably in excess of the stoichiometric values, owing to the limitation in contacting efficiencies imposed by the particle sizes of the materials.

A suitably reactive, gaseous depressant such as ammonia would obviously offer great advantages as diffusion would ensure rapid and efficient contacting of the SO_3.

When ammonia was injected into the "cool" chamber of the experimental furnace at a flue-gas temperature of about 300 C, water dewpoints were obtained with all concentrations above 0.021 per cent by weight on fuel (Fig. 8). If it is assumed that the mean SO_3 content of the flue gases is 0.003 per cent by volume on the dry gas, and that the oil feed rate is 6.8 lbs per hr (a mean rate for the runs made) the required stoichiometric concentration of ammonia to neutralize the SO_3 is 0.06 per cent by weight on the fuel feed. For concentrations of ammonia between 0.021 and 0.056 per cent by weight of fuel feed the condensed film on the glass between the electrodes provided an acid reaction to methyl orange indicator; at ammonia concentrations at and above 0.074 per cent by weight of feed the reactions were neutral to methyl orange (pH 4.6). The observed acidic reactions must have been due to the presence of ammonium bisulfate, and virtually complete neutralization therefore occurred at an ammonia concentration of between 0.056 and 0.074 per cent by weight of fuel; this is in good agreement with the calculated figure of 0.06 per cent by weight of fuel.

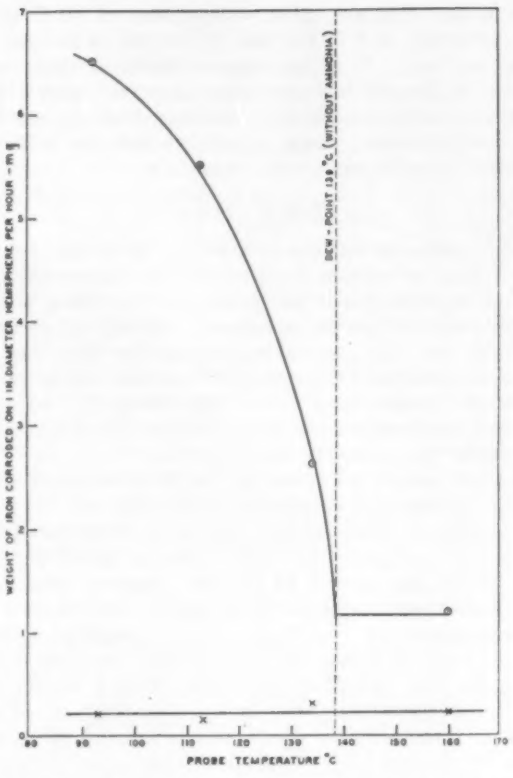


Fig. 9—Corrosion measurements with and without ammonia injection

× With ammonia injection. ⊙ Without ammonia injection.

Measurements were also made of the corrosion produced by the flue gases, using a corrosion probe, both with and without ammonia injection at temperatures ranging from 21 C above to 46 C below the acid dewpoint. The ammonia was injected at a concentration of 0.086 per cent by weight of fuel feed.

Curves of the iron contents of the probe washings versus the temperature of the probe surface are given in Fig. 9; the curves are based on mean values from duplicate tests.

The maximum corrosion without ammonia injection was 6.5 mg of iron at a probe temperature of 93 C (46 C below the acid dewpoint); with ammonia injection the corrosion was reduced to 0.2 mg iron. These values were obtained when a 1-in. diam hemisphere was exposed for one hour; the corresponding corrosion rates are 15.4 mg/cm² day (0.284 in./yr penetration) and 0.47 mg/cm² day (0.0087 in./yr penetration).

The surface of the probe head showed no tarnishing or dulling of the surface finish when ammonia was injected and the appearance of the surface of the head, after the deposits of ammonium salts had been washed off, was indistinguishable from its polished appearance immediately prior to each test.

The initial dissociation temperature of ammonia is about 600 C, but decomposition is slow at this temperature; 75 per cent is decomposed at 1100 C, and complete decomposition occurs at 1300 C (19):

$$2NH_3 \overset{600\ C}{\rightleftarrows} N_2 + 3H_2 \qquad (2)$$

In the presence of a flame, however, this reaction will go completely to the right as the hydrogen is burned and progressive decomposition will occur at a temperature of about 600 C. The temperature at which the gas can be injected into the combustion gases without decomposition is therefore confined to the range below 600 C.

No information can be found in the literature on the gas phase reactions between ammonia and SO_3 in the presence of water vapor. However, a consideration of the reactions involved in the thermal decomposition of ammonium sulfate and of the properties of ammonium bisulfate are of assistance in obtaining the most likely sequence of the reactions taking place.

On heating ammonium sulfate the following reaction occurs at 300 to 350 C (20):

$$(NH_4)_2SO_4 \rightleftarrows NH_4HSO_4 + NH_3 \qquad (3)$$
$$\textit{solid} \qquad \textit{liquid} \qquad \textit{gas}$$

The ammonium bisulfate produced is liquid at this temperature, because its melting point is 147 C. On further heating, the ammonium bisulfate vaporizes at 400 to 500 C without decomposition.

If the reactions which occur when ammonia is brought into contact with SO_3 at 350 C in the presence of water vapor are considered, it is reasonable to suppose that ammonium bisulfate will first be formed.

$$SO_3 + NH_3 + H_2O \overset{350\ C}{\rightarrow} NH_4HSO_4 \qquad (4)$$
$$\textit{gas} \quad \textit{gas} \quad \textit{gas} \qquad \textit{liquid}$$

A further reaction will occur in the presence of excess ammonia at temperatures of 300 to 350 C.

$$NH_4HSO_4 + NH_3 \rightleftarrows (NH_4)_2SO_4 \qquad (5)$$
$$\textit{liquid} \qquad \textit{gas} \qquad \textit{solid}$$

As this is a gas/liquid reaction, the reaction rate will be considerably slower than the previous reaction (4), which occurs in the gaseous phase, and may not reach completion. Even when a reasonable excess of ammonia is used, the products of reaction may contain a proportion of the acid salt.

If ammonia is injected into the flue-gas stream in a boiler at a temperature of about 350 C, the SO_3 should react with the ammonia according to the preceding reactions, but the SO_2 in the flue gases will not combine with the ammonia to form ammonium sulfite above a temperature of about 150 C. Ammonia will thus selectively remove the SO_3 from combustion gases if injected in the temperature range 600 to 150 C, leaving the SO_2 uncombined.

At temperatures between about 500 and 147 C, the ammonium bisulfate formed is liquid and a proportion will tend to solidify on cooled heat-exchange surfaces, forming an adherent deposit; the remainder will be carried away as suspended droplets in the flue-gas stream. The normal sulfate, which exists as a solid below about 350 C, will tend to adhere to a certain extent to the molten bisulfate before this solidifies. Under normal running conditions the deposits will remain dry, and corrosion should be negligible.

Discussion

The work establishing the relationship between the dewpoints and SO_3 contents of flue gases and the sulfur contents of the fuels was done at only one combustion chamber temperature of 1000 C; this temperature was measured by a thermocouple positioned centrally in the furnace approximately one foot from the end of the flame. The flame temperature has been calculated as 1620 C under the conditions employed during the tests. The quantitative results shown cannot therefore be applied to installations operating with flame temperatures differing appreciably from this, as it is known that the production of SO_3 increases with increasing flame temperature; this is probably due to the higher concentration of atomic oxygen in the flame zone at higher temperatures. The results are likewise only applicable to furnaces operating with 25 per cent excess air.

The curve showing the relationship betwen the dewpoint of the flue gases and the sulfur content of the fuel (Fig. 3) includes some dewpoint measurements on an industrial water-tube boiler. These results agree with other results, plotted in Fig. 3, obtained during work on experimental furnaces in which the catalytic oxidation of SO_2 was kept to a minimum; this suggests that there was no significant catalysis in the industrial boiler. It is therefore probable that the results can be applied to many industrial boilers, provided that the flame temperatures and operating conditions are similar.

Important requirements for dewpoint depressants to be used with fuel oils are:

(*a*) The total cost of the depressant treatment must be commensurate with the advantages conferred.

(*b*) Any additional equipment (for example, injection pumps, stirrers) must be simple to operate and to maintain, and of low capital cost.

(*c*) If the depressant is oil-soluble, it must not come out of solution or precipitate sludge during storage.

Oil-soluble depressants have several advantages over insoluble materials:

(*a*) No additional operations by the user are necessary (for example, auxiliary injection or agitation) as the depressant can be compounded with the oil before distribution.

(*b*) The additive is dispersed uniformly, and if the additive is properly compounded the risk of precipitation should be slight.

Materials which successfully eliminated the acid dewpoint are listed in Table II, which also gives the costs of treatment (for materials only).

The oil-soluble depressants tested (magnesium and zinc naphthenates, and two other magnesium soaps made from a blown pork-fat and fatty-acid pitch) all suffer from the disadvantage that only one hydrogen atom of the high-molecular-weight acid is replaceable by the metal, which is the active constituent, and consequently a large concentration of the fatty acid is required to hold the metallic element in solution.

If the fatty acid is assumed to consist only of stearic acid the ratio of acid to metal is approximately 24:1 by weight. The fatty-acid contents of the blown pork-fat and the fatty-acid pitch were 77 per cent and 40 per cent by weight respectively, so that the ratios of fat

TABLE II—COSTS OF TREATMENT WITH MATERIALS WHICH SUCCESSFULLY ELIMINATED THE ACID DEWPOINT

Material	Method of addition	Minimum concn. of feed to eliminate acid dewpoint, % wt.	Cost of treatment per ton of oil (materials only) L	s.	d.
Ammonia	Gas injected into flue gases at about 350 C.	0.06		1	2
Zinc dust	Suspension in gas oil to fuel feed	0.47		10	11
Dolomite	Suspension in gas oil to fuel feed	0.80 (Ca + Mg)		17	6
Magnesium oxide	Suspension in gas oil to fuel feed	0.35 (Mg)	1	8	7
Magnesium soap	Solution in gas oil to fuel feed	0.15 (Mg)	1	14	1
Zinc naphthenate	Solution in gas oil to fuel feed	0.22 (Zn)	4	15	6
Magnesium naphthenate	Solution in gas oil to fuel feed	0.15 (Mg)	7	5	7

and fatty acid to magnesium in the additives were approximately 31:1 and 60:1 by weight. When the minimum concentration of magnesium (0.15 per cent by weight) was used to eliminate the acid dewpoint completely the treated fuels contained 4.33 per cent and 9.03 per cent by weight of aliphatic material respectively. For this reason the oil-soluble depressants are expensive, and their high costs far outweigh their inherent advantages.

Treatments with zinc dust, dolomite and magnesium oxide are cheaper than with oil-soluble materials, but as these materials have to be introduced in a very finely-divided state the cost is still high. Pumps and agitators are also required for injecting and handling these materials; this factor is likely to make their employment still less attractive to a potential user.

The addition of ammonia to the combustion gases at a temperature of about 300 C was the most effective and cheapest method found of eliminating the acid dewpoint. The advantages of using a gaseous depressant are considerable as the contacting efficiency is very high, owing to rapid diffusion. Although ammonia cannot be initially compounded with the oil, but has to be injected into the combustion gases at low temperature, the equipment required is simple and requires negligible maintenance. The gas is cheap, readily available in large quantities and of uniform quality, in contrast with most of the other materials which have been used as dewpoint depressants. Recovery of ammonium sulfate, from the soot and ash collected in cyclones, for sale as fertilizer might also be economically practicable.

This paper has described the ammonia-injection process as applied to oil-fired equipment, but its application to solid-fuel installations should present few problems. Power-station and industrial boilers, cement, brick and pottery kilns, whether fired by oil or solid fuel, have their specific corrosion problems associated with acid condensation, and it is hoped that a widespread application of the principles described may provide a cure for these difficulties, and at the same time increase plant efficiencies, and so make a significant contribution to the conservation of fuel supplies throughout the world.

Acknowledgments

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Three Florida Utilities Submit Proposal for Nuclear Power Plant

Lewis L. Strauss, Chairman of the Atomic Energy Commission, announced recently that three Florida electric power companies, constituting the Florida Nuclear Power Group, have submitted a formal proposal to the Commission for the development, design and construction of the nation's first large-scale nuclear power plant using natural uranium as its fuel.

The proposal of the Florida group calls for a heavy water-moderated, gas-cooled reactor, fueled with natural uranium, and having a net electrical capacity of 136,000 kilowatts. A preliminary estimate places the cost of building the plant at approximately $40,000,000.

Members of the Florida Nuclear Power Group are: the Florida Power Corporation of St. Petersburg, the Florida Power and Light Company of Miami, and the Tampa Electric Company of Tampa. The General Nuclear Engineering Corporation of Dunedin, Florida, which is headed by Dr. Walter H. Zinn, former director of the Commission's Argonne National Laboratory, has been engaged to design the reactor and carry out research and development work, including development of the natural uranium fuel elements.

The role of fuel sources in determining the level of civilization is viewed against the backdrop of past and present cultures. The author points out that nuclear fuels offer considerable promise as future energy sources and indicates certain ways to prepare for an orderly transition.

Energy Resources and Our Future[*]

By Rear Adm H. G. Rickover, USN[1]

WE LIVE in what historians may some day call the Fossil Fuel Age. Today coal, oil, and natural gas supply 93 per cent of the world's energy; water power accounts for only 1 per cent; and the labor of men and domestic animals the remaining 6 per cent. This is a startling reversal of corresponding figures for 1850—only a century ago. Then fossil fuels supplied 5 per cent of the world's energy, and men and animals 94 per cent. Five-sixths of all the coal, oil, and gas consumed since the beginning of the Fossil Fuel Age has been burned up in the last 55 years.

Once in full swing, fossil fuel consumption has accelerated at phenomenal rates. All of the fossil fuels used before 1900 would not last five years at today's rates of consumption.

Nowhere are these rates higher and growing faster than in the United States. Our country, with only 6 per cent of the world's population, uses one-third of the world's total energy input; this proportion would be even greater except that we use energy more efficiently than other countries. Each American has at his disposal, each year, energy equivalent to that obtainable from eight tons of coal. This is six times the world's per capita energy consumption. Though not quite so spectacular, corresponding figures for other highly industrialized countries also show above average consumption figures. The United Kingdom, for example, uses more than three times as much energy as the world average.

With high energy consumption goes a high standard of living. Thus the enormous fossil energy which we in this country control feeds machines which make each of us master of an army of mechanical slaves. Man's muscle power is rated at 35 watts continuously, or one-twentieth horsepower. Machines therefore furnish every American industrial worker with energy equivalent to that of 244 men, while at least 2000 men push his automobile along the road, and his family is supplied with 33 faithful household helpers. Each locomotive engineer controls energy equivalent to that of 100,000 men; each jet pilot of 700,000 men. Truly, the humblest American enjoys the services of more slaves than were once owned by the richest nobles, and lives better than most ancient kings. In retrospect, and despite wars, revolutions, and disasters, the hundred years just gone by may well seem like a Golden Age.

Energy Balances

Whether this Golden Age will continue depends entirely upon our ability to keep energy supplies in balance with the needs of our growing population. Possession of surplus energy is, of course, a requisite for any kind of civilization, for if man possesses merely the energy of his own muscles, he must expend all his strength—mental and physical—to obtain the bare necessities of life.

Slave labor was necessary for the city states and the empires of antiquity; they frequently had slave populations larger than their free citizenry. As long as slaves were abundant and no moral censure attached to their ownership, incentives to search for alternative sources of energy were lacking; this may well have been the single most important reason why engineering advanced very little in ancient times.

A reduction of per capita energy consumption has always in the past led to a decline in civilization and a reversion to a more primitive way of life. For example, exhaustion of wood fuel is believed to have been the primary reason for the fall of the Mayan Civilization on this continent and of the decline of once fluorishing civilizations in Asia. India and China once had large forests as did much of the Middle East.—Deforestation not only lessened the energy base but had a further disastrous effect: lacking plant cover, soil washed away, and with erosion the nutritional base was reduced as well.

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[1] Abstracted from a banquet address at the Annual Scientific Assembly of the Minnesota State Medical Association, St. Paul, Minn., May 14, 1957.

Another cause of declining civilization comes with pressure of population on available land. A point is reached where the land can no longer support both the people and their domestic animals. Horses and mules disappear first, finally even the versatile water buffalo is displaced by man who is two and one half times as efficient an energy converter as are draft animals. It must al vays be remembered that while domestic animals and agricultural machines increase productivity *per man*, maximum productivity *per acre* is achieved only by intensive manual cultivation.

Asia failed to keep technological pace with the needs of her growing populations and sank into such poverty that in many places man has become again the primary source of energy, since other energy converters have become too expensive. This must be obvious to the most casual observer. What this means is quite simply a reversion to a more primitive stage of civilization with all that it implies for human dignity and happiness.

Where slavery represented a major source of energy, its abolition had the immediate effect of reducing energy consumption. Thus when the time-honored institution came under moral censure by Christianity, civilization declined until other sources of energy could be found. Slavery is incompatible with Christian belief in the worth of the humblest individual as a child of God. As Christianity spread through the Roman Empire and masters freed their slaves—in obedience to the teaching of the Church—the energy base of Roman civilization crumbled. This, some historians believe, may have been a major factor in the decline of Rome and the temporary reversion to a more primitive way of life during the Dark Ages. Slavery gradually disappeared throughout the Western world, except in its milder form of serfdom. That it was revived a thousand years later merely shows man's ability to stifle his conscience—at least for a while—when his economic needs are great. Eventually even the needs of overseas plantation economies did not suffice to keep alive a practice so deeply repugnant to Western man's deepest convictions.

Manpower vs. Nature's Power

It may well be that it was unwillingness to depend on slave labor for their energy needs which turned the minds of medieval Europeans to search for alternative sources of energy, thus sparking the Power Revolution of the Middle Ages which, in turn, paved the way for the Industrial Revolution of the 19th Century. When slavery disappeared in the West engineering advanced. Men began to harness the power of nature by utilizing water and wind as energy sources. The sailing ship, in particular, which replaced the slave-driven galley of antiquity, was vastly improved by medieval shipbuilders and became the first machine enabling man to control large amounts of inanimate energy.

The next important high-energy converter used by Europeans was gun powder—an energy source far superior to the muscular strength of the strongest bowman or lancer. With ships that could navigate the high seas and arms that could outfire any hand weapon, Europe was now powerful enough to preempt for herself the vast empty areas of the Western Hemisphere into which she poured her surplus populations to build new nations of European stock. With these ships and arms she also gained political control over populous areas in Africa and Asia from which she drew the raw materials needed to speed her industrialization, thus complementing her naval and military dominance with economic and commercial supremacy.

When a low-energy society comes in contact with a high-energy society, the advantage always lies with the latter. The Europeans not only achieved standards of living vastly higher than those of the rest of the world, but they did this while their population was growing at rates far surpassing those of other peoples. In fact, they doubled their share of the total world population in the short span of three centuries. From one-sixth in 1650, the people of European stock increased to almost one-third of total world population by 1950.

Almost all of today's low-energy countries have a population density so great that it perpetuates dependence on intensive manual agriculture which alone can yield barely enough food for their people. They do not have enough acreage, per capita, to justify using domestic animals or farm machinery, although better seeds, better soil management, and better hand tools could bring some improvement. A very large part of their working population must nevertheless remain on the land, and this limits the amount of surplus energy that can be produced. Most of these countries must choose between using this small energy surplus to raise their very low standard of living or postpone present rewards for the sake of future gain by investing the surplus in new industries. The choice is difficult because there is no guarantee that today's denial may not prove to have been in vain. This is so because of the rapidity with which public health measures have reduced mortality rates, resulting in population growth as high or even higher than that of the high-energy nations. Theirs is a bitter choice; it accounts for much of their anti-Western feeling and may well portend a prolonged period of world instability.

No further elaboration is needed to demonstrate the significance of energy resources for our own future. Our civilization rests upon a technological base which requires enormous quantities of fossil fuels. What assurance do we then have that our energy needs will continue to be supplied by fossil fuels? The answer is—in the long run—none.

The Future for Fossil Fuels

The earth is finite. Fossil fuels are not renewable. In this respect our energy base differs from that of all civilizations. They *could* have maintained their energy supply by careful cultivation. We cannot. Fuel that has been burned is gone forever. Fuel is even more evanescent than metals. Metals, too, are non-renewable resources threatened with ultimate extinction, but something can be salvaged from scrap. Fuel leaves no scrap and there is nothing man can do to rebuild exhausted fossil fuel reserves. They were created by solar energy 500 million years ago and took eons to grow to their present volume.

In the face of the basic fact that fossil fuel reserves are finite, the exact length of time these reserves will last is important in only one respect: the longer they last, the more time do we have to invent ways of living off renewable or substitute energy sources and to adjust our economy to the vast changes which we can expect from such a shift.

Current estimates of fossil fuel reserves vary to an astonishing degree. In part this is because the results differ greatly if cost of extraction is disregarded or if in calculating how long reserves will last, population growth is not taken into consideration; or, equally important, not enough weight is given to increased fuel consumption required to process inferior or substitute metals. We are rapidly approaching the time when exhaustion of better grade metals will force us to turn to poorer grades requiring in most cases greater expenditure of energy per unit of metal.

It is an unpleasant fact that according to our best estimates, total fossil fuel reserves recoverable at not over twice today's unit cost, are likely to run out at some time between the years 2000 and 2050, if present standards of living and population growth rates are taken into account. Oil and natural gas will disappear first, coal last. There will be coal left in the earth, of course. But it will be so difficult to mine that energy costs would rise to economically intolerable heights, so that it would then become necessary either to discover new energy sources or to lower standards of living drastically.

For more than one hundred years we have stoked ever growing numbers of machines with coal; for fifty years we have pumped gas and oil into our factories, cars, trucks, tractors, ships, planes, and homes without giving a thought of the future. Occasionally the voice of a Cassandra has been raised only to be quickly silenced when a lucky discovery revised estimates of our oil reserves upward, or a new coal field was found in some remote spot. Fewer such lucky discoveries can be expected in the future, especially in industrialized countries where extensive mapping of resources has been done. Yet the popularizers of scientific news would have us believe that there is no cause for anxiety, that reserves will last thousands of years, and that before they run out science will have produced miracles. Our past history and security have given us the sentimental belief that the things we fear will never really happen—that everything turns out right in the end. But, prudent men will reject these tranquilizers and prefer to face the facts so that they can plan intelligently for the needs of their posterity.

Looking into the future, from the mid-20th Century, we cannot feel overly confident that present high standards of living will of a certainty continue through the next century and beyond. Fossil fuel costs will soon definitely begin to rise as the best and most accessible reserves are exhausted, and more effort will be required to obtain the same energy from remaining reserves. It is likely also that liquid fuel synthesized from coal will be more expensive. Can we feel certain that when economically recoverable fossil fuels are gone science will have learned how to maintain a high standard of living on *renewable* energy sources?

Renewable Energy Sources

I believe it would be wise to assume that the principal renewable fuel sources which we can expect to tap before fossil reserves run out will supply only 7 to 15 per cent of future energy needs. The five most important of these renewable sources are wood fuel, farm wastes, wind, water power, and solar heat.

Wood fuel and farm wastes are dubious as substitutes because of growing food requirements to be anticipated. Land is more likely to be used for food production than for tree crops; farm wastes may be more urgently needed to fertilize the soil to fuel machines.

Wind and water power can furnish only a very small percentage of our energy needs. Moreover, as with solar energy, expensive structures would be required, making use of land and metals which will also be in short supply. Nor would anything we know today justify putting too much reliance on solar energy though it will probably prove feasible for home heating in favorable localities and for cooking in hot countries which lack wood, such as India.

Nuclear Sources

More promising is the outlook for nuclear fuels. These are not, properly speaking, renewable energy sources, at least not in the present state of technology, but their capacity to "breed" and the very high energy output from small quantities of fissionable material, as well as the fact that such materials are relatively abundant, do seem to put nuclear fuels into a separate category from exhaustible fossil fuels. The disposal of radioactive wastes from nuclear power plants is, however, a problem which must be solved before there can be any widespread use of nuclear power.

Another limit in the use of nuclear power is that we do not know today how to employ it otherwise than in large units to produce electricity or to supply heating. Because of its inherent characteristics, nuclear fuel cannot be used directly in small machines, such as cars, trucks, or tractors. It is doubtful that it could in the foreseeable future furnish economical fuel for civilian airplanes or ships, except very large ones. Rather than nuclear locomotives, it might prove advantageous to move trains by electricity produced in nuclear central stations. We are only at the beginning of nuclear technology, so it is difficult to predict what we may expect.

Transportation—the lifeblood of all technically advanced civilizations—seems to be assured, once we have borne the initial high cost of electrifying railroads and replacing buses with streetcars or interurban electric trains. But, unless science can perform the miracle of synthesizing automobile fuel from some energy source as yet unknown or unless trolley wires power electric automobiles on all streets and highways, it will be wise to face up to the possibility of the ultimate disappearance of automobiles, trucks, buses, and tractors.

Today the automobile is the most uneconomical user of energy. Its efficiency is 5 per cent compared with 23 per cent for the diesel-electric railway. It is the most ravenous devourer of fossil fuels, accounting for over half of the total oil consumption in this country. And the oil we use in the United States in one year took nature about 14 million years to create. Curiously, the automobile, which is the greatest single cause of the rapid exhaustion of oil reserves, may eventually be the first fuel consumer to suffer. Reduction in automotive use would necessitate an extraordinarily costly reorganization of the pattern of living in industrialized nations, particularly in the United States. It would seem prudent to bear this in mind in future planning of cities and industrial locations.

Our present known reserves of fissionable materials are many times as large as our net economically recoverable reserves of coal. A point will be reached before this

century is over when fossil fuel costs will have risen high enough to make nuclear fuels economically competitive. Before that time comes we shall have to make great efforts to raise our entire body of engineering and scientific knowledge to a higher plateau. We must also induce many more young Americans to become metallurgical and nuclear engineers. Else we shall not have the knowledge or the people to build and run the nuclear power plants which ultimately may have to furnish the major part of our energy needs. If we start to plan now, we may be able to achieve the requisite level of scientific and engineering knowledge before our fossil fuel reserves give out, but the margin of safety is not large. This is also based on the assumption that atomic war can be avoided and that population growth will not exceed that now calculated by demographic experts.

Effect of War

War, of course, cancels all man's expectations. Even growing world tension just short of war could have far-reaching effects. In this country it might, on the one hand, lead to greater conservation of domestic fuels, to increase oil imports, and to an acceleration in scientific research which might turn up unexpected new energy sources. On the other hand, the resulting armaments race would deplete metal reserves more rapidly, hastening the day when inferior metals must be utilized with consequent greater expenditure of energy. Underdeveloped nations with fossil fuel deposits might be coerced into withholding them from the free world or may themselves decide to retain them for their own future use. The effect upon Europe, which depends on coal and oil imports, would be disastrous and we would have to share our own supplies or lose our allies.

Pressure of Population

Barring atomic war or unexpected changes in the population curve, we can count on an increase in world population from two and one-half billion today to four billion in the year 2000; six to eight billion by 2050. The United States is expected to quadruple its population during the 20th Century—from 75 million in 1900 to 300 million in 2000—and to reach at least 375 million in 2050. This would almost exactly equal India's present population which she supports on just a little under half of our land area.

In the 8000 years from the beginning of history to the year 2000 A.D. world population will have grown from 10 million to 4 billion, with 90 per cent of the growth taking place during the last 5 per cent of that period, in 400 years. It took the first 3000 years of recorded history to accomplish the first doubling of population, 100 years for the last doubling, but the next doubling will require only 50 years. Calculations give us the astonishing estimate that one out of every 20 human beings born into this world is alive today.

Much of the wilderness which nurtured what is most dynamic in the American character has now been buried under cities, factories, and suburban developments where each picture window looks out on nothing more inspiring than the neighbor's back yard with the smoke of his fire in the wire basket clearly visible.

Life in crowded communities cannot be the same as life on the frontier. We are no longer free, as was the pioneer, to work for our own immediate needs regardless of the future. We are no longer as independent of men and of government as were Americans two or three generations ago. An even larger share of what we earn must go to solve problems caused by crowded living—bigger governments; bigger city, state, and Federal budgets to pay for more public services. Merely to supply us with enough water and to carry away our waste products gets daily more difficult and expensive. More laws and enforcement agencies are needed to regulate human relations in urban industrial communities and on crowded highways than in the America of Thomas Jefferson.

Certainly no one like taxes, but we must become reconciled to larger taxes in the larger America of tomorrow.

Responsibilities to the Future

I suggest that this is a good time to think soberly about our responsibilities to our descendants—those who will ring out the Fossil Fuel Age. Our greatest responsibility, as parents and as citizens, is to give America's youngsters the best possible education. We need the best teachers and enough of them to prepare our young people for a future immeasurably more complex than the present, and calling for ever larger numbers of competent and highly trained men and women. This means that we must not delay building more schools, colleges, and playgrounds. It means that we must reconcile ourselves to continuing higher taxes to build up and maintain at decent salaries a greatly enlarged corps of much better trained teachers, even at the cost of denying ourselves such momentary pleasures as buying a bigger new car, or a TV set, or houshold gadget. We should find—I believe—that these small self denials would be far more than offset by the benefits they would buy for tomorrow's America. We might even—if we wanted—give a break to these youngsters by cutting fuel and metal consumption a little here and there so as to provide a safer margin for the necessary adjustments which eventually must be made in a world without fossil fuels.

National Assn. of Power Engineers Hold Diamond Jubilee Convention

Grand Rapids Chapter No. 16 of National Association of Power Engineers were hosts to their organization's Diamond Jubilee National Convention, June 23 to 28, 1957, at the Pantlind Hotel, Grand Rapids, Michigan. With it they staged a Power Show in the Grand Rapids Civic Auditorium.

The NAPE membership and delegates under its new president, Walter A. Lamb. made full salute to the men who had formed the organization and built it up over the years. One of the features of the technical sessions, however, were reports on the self-education program the NAPE sponsored about a year or so ago in conjunction with the University of Wisconsin.

This course at relatively low cost to the beneficiaries affords schooling in steam plant operation, refrigeration and air conditioning with special courses in mathematics, chemistry and physics at high school and college levels. Response has been excellent with well over 2000 inquiries and, interestingly, an increase in NAPE membership of roughly 1000.

Steam Calorimetry

by J. H. POTTER*

Stevens Institute of Technology

The art and science of steam calorimetry is reviewed. Descriptions and equations are presented for the principal types of steam calorimeters. The importance of calorimetry is considered in terms of industry and engineering education.

DISCUSSIONS on the measurement of the quality of steam dominated many of the early meetings of the ASME. Professor R. H. Thurston (1)[1] credited Hirn as the man who first appreciated the importance of steam quality measurements in boiler testing, and claimed that Hirn had worked on this problem over the period 1865–1871.

Steam calorimeters based upon many scientific principles have been proposed over the years. The 1940 Code (2) dealt with a wide range of instruments of both practical and laboratory types. Diederichs and Andrae (3) presented a very complete picture of the art of steam calorimetry, including many of the instruments developed at Cornell University.

The present paper was based upon studies made for the committee currently revising the code on steam quality (PTC-19.11). The sources investigated were (*a*) the technical journals, (*b*) the patent literature, and (*c*) the instrument manufacturers. The study was restricted to the calorimeters and did not include sampling procedures. These account for errors greater than those of the calorimeter as has frequently been demonstrated. Sampling methods are explained in detail in a number of sources (2–4).

Wet steam is generally considered to be an equilibrium mixture of dry steam and water at the same temperature and pressure. The quality of wet steam may be defined as the percentage by weight of saturated vapor in an isothermal mixture of saturated vapor and saturated liquid. The function of the steam calorimeter is to provide information from which the quality may be determined.

Steam calorimeters may be broadly classified according to operation, involving (*a*) mass balance, (*b*) heat balance, (*c*) energy balance, or (*d*) combinations of the foregoing. The separating calorimeter (5) works on a mass balance basis, mechanically separating the liquid fraction. Heat balance methods are employed in the barrel and jet types (6) where the steam sample is condensed as it mixes with a known mass of liquid, and also in the surface condenser form (7). The same principle is used in the external superheating calorimeter (8–9). Throttling calorimeters constitute the group depending upon energy balance. The earliest worker in this field was Peabody (10–11), who in 1888 explained the theory of the throttling calorimeter and described his experimental work.

On many of the early boiler tests the calorimetric measurements were plagued with sampling difficulties (12–14), and these in turn gave rise to many interesting conjectures as to how dryness should be measured. Denton (15) claimed that he could judge the quality of steam in a pipe line by observing the color and form of the steam jet issuing from a small valve. It may well be that the state of the art of sampling in those days was sufficiently uncertain that it partially justified such a technique.

The "universal" calorimeter combined the throttling and separating types in one instrument, thus extending the range of moisture in which satisfactory measurements could be made. In a paper published in 1921, Upton (16) predicted that only the throttling and universal calorimeters would survive. This has been borne out in practice, as the more complicated steam calorimeters are found only in college laboratories.

Theory

The several types of steam calorimeters can be reduced to a few simple configurations such as those shown in Figs. 1 through 5. Analysis of each of these types is based upon perfect steam sampling and overall adiabatic performance.

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* Member, ASME Sub-Committee (F), Power Test Codes Committee No. 19, on Instruments and Apparatus.

[1] Numbers in parentheses refer to References at the end of the article.

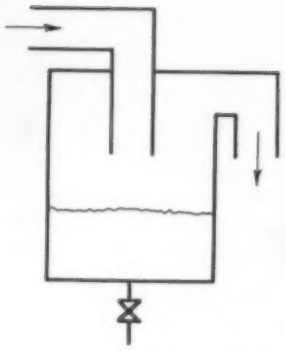

Fig. 1—The separating calorimeter wherein water droplets are removed from steam by sharp change of steam path

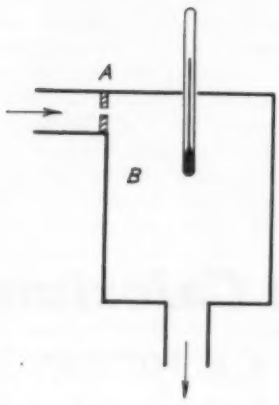

Fig. 2—Throttling calorimeter directs steam sample through an orifice and dissipates kinetic energy of jet in chamber, *B*

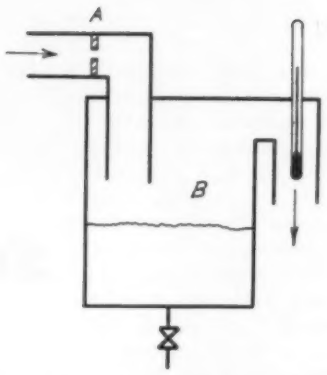

Fig. 3—Universal calorimeter has several variations. One above throttles steam through orifice and separates moisture in chamber, *B*

In Fig. 1, the separating calorimeter is shown. Wet steam enters the instrument at the top. Water droplets are removed by deflecting the steam path through 180 degrees. For low rates of steam flow, only dry saturated vapor is found at exit. Carpenter (5) claimed that on the basis of nearly one-hundred observations the exit steam quality averaged "99.998%."

If the enthalpy of the steam in the main is designated h_1, this may be represented as the sum of the enthalpy of saturated liquid, h_{f_1}, and a fraction, x, of the enthalpy of vaporization, h_{fg1}:

$$h_1 = h_{f_1} + X(h_{fg})_1 \qquad (1)$$

From the definition of quality, equation (1) may be re-written in terms of w pounds of saturated liquid and $(1 - w)$ pounds of saturated vapor:

$$h_1 = w(h_{f_1}) + (1 - w)(h_g)_1$$

and

$$X = \frac{(1 - w)}{(w) + (1 - w)} = (1 - w) \qquad (2)$$

hence for each pound of wet steam entering the calorimeter, the quality can be found by subtracting the weight fraction of separated moisture from unity.

The throttling calorimeter is shown diagrammatically in Fig. 2. Steam is throttled during the passage through the orifice A, emerging with a high velocity. In the calorimeter chamber B, the kinetic energy of this steam jet is dissipated without doing any work. As a result the enthalpy is restored to the value originally present in the steam main. If the thermometer in the calorimeter chamber indicates that the steam is superheated, the thermal enthalpy, h_2, can be found from steam tables. The quality may then be determined:

$$h_1 = h_{f_1} + X(h_{fg})_1 = h_2$$

and

$$X = \frac{h_2 - h_{f1}}{h_{fg1}} \qquad (3)$$

If the steam in the calorimeter chamber is not superheated, the moisture in the line is too high for this type of instrument. The quality range may be extended by either (*a*) reducing the backpressure or (*b*) using the throttling calorimeter in conjunction with a separating type. Theoretical discussions of the throttling calorimeter are generally available (3, 17, 18); some of the technical papers include charts for the rapid calculation of quality from the measured variables (19–20).

At the present time only one manufacturer offers a line of throttling calorimeters. This is due in part to the fact that many successful calorimeter designs involve only an assembly of standard pipe fittings. One such design is shown in Fig. 6. The unit is made from one inch fittings including a standard return bend in which provision has been made for a drain cock at E. The vertical legs are made from 8-in. lengths of 1-in. pipe. There is an $^1/_8$-in. diameter orifice in the steel nipple, A, which terminates in $^3/_4$-in. pipe threads. A $^3/_4 \times 1$-in. coupling is used at B. A 1-in. pipe plug, C, closes the top of the left tee. A rubber stopper, pierced to accommodate the calorimeter thermometer, is shown at D. The entire instrument is heavily insulated with hair felt.

The ease with which a throttling calorimeter can be built from pipe fittings may be offset by difficulties in operation. Calibration is always desirable, especially in the absence of internal radiation shields. Also, the steam flow must bear a reasonable relationship to the calorimeter dimensions, as has been noted in the Code (2).

Very few new calorimeter designs have been proposed. Several desirable features have been combined in the instrument shown in Fig. 7. This unit was designed and built by Professor J. A. Polson at the University of Illinois. The small orifices used in calorimeters sometimes become clogged with dirt or scale. This difficulty is obviated by drilling the orifices in a removable cartridge as shown in the center of Fig. 7. Also, the vertical cylinder surrounding the thermometer well is blanketed on each side with low pressure steam, and acts as a radiation shield. The body and fittings of the instrument are machined from bronze castings.

One form of the universal calorimeter is shown in Fig. 3. Here the steam is throttled at the orifice A, and partially dried. The remaining moisture is removed in the separating compartment B. As the calorimeter temperature will be that of vapor at the chamber pressure, the

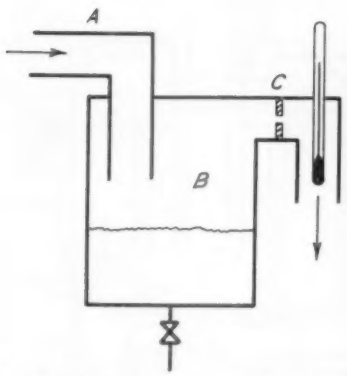

Fig. 4—The reverse approach to that employed in Fig. 3 is shown above where mechanical separation occurs first and then the steam is throttled

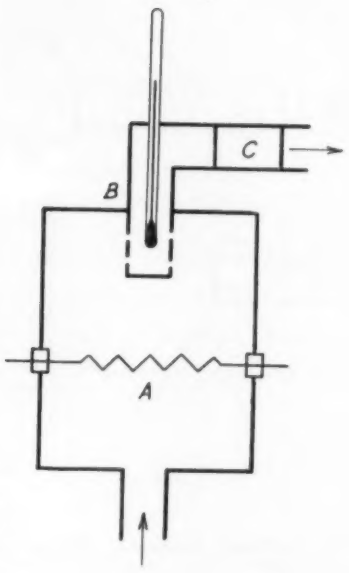

Fig. 5—Electrically heated calorimeter passes steam over an electric heating element, then through a thermometer chamber, *B*

quality calculation must be based upon the assumption that the steam leaves as saturated vapor. The quality undergoes a change during the passage through the orifice:

$$h_1 = h_{f1} + (x_1)h_{fg1} = h_2 = h_{f2} + (x_2)h_{fg2} \qquad (4)$$

The quality in the calorimeter chamber is determined by measuring the separated water, w:

$$(x_2) = (1 - w),$$

and,

$$(x_1) = \left\{\frac{h_{f2} + (1 - w)h_{fg2} - h_{f1}}{h_{fg1}}\right\} \qquad (5)$$

A somewhat better universal calorimeter is shown in Fig. 4. Here the steam undergoes mechanical separation prior to throttling. This permits superheating of the exit steam and makes for a much more satisfactory instrument. Barrus (22) described tests with this type of calorimeter in which the orifice characteristics were checked by condensing and weighing all of the steam used by the instrument. Stott and Piggott (23) used such a device on a steam turbine test, operating with back pressures as low as 2 in. Hg absolute.

A more general expression for the quality as found by this type of universal instrument may be derived if it is assumed that the separator removes only w' pounds of liquid of the w pounds present per pound of wet steam:

$$h_{f1} + (x_1)h_{fg1} = (w')h_{f1} + \{(w - w')h_{f1} + (1 - w)h_{g1}\} \qquad (6)$$

As less than a pound of steam flows through the orifice:

$$(x_1) = (1 - w')(x_2) \qquad (7)$$

The quality found from throttling will be:

$$(x_2) = \left\{\frac{(1 - w)}{(1 - w) + (w - w')}\right\} = \left\{\frac{(1 - w)}{(1 - w')}\right\} \qquad (8)$$

However the passage through the orifice produces superheated steam at exit:

$$h_{f1} + (x_2)h_{fg1} = h_2$$

$$(x_2) = (h_2 - h_{f1})/h_{fg1}$$

From equation (7):

$$(x_1) = (1 - w')(h_2 - h_{f1})/h_{fg1} \qquad (9)$$

A general discussion of steam calorimeters would not be complete without some mention of those using electric heater elements to dry the vapor. Thomas (24) introduced an electrically heated calorimeter of the type shown in Fig. 5. The steam sample was passed over an electric heating element, A, then through a thermometer chamber, B. At C, a sight glass was provided. In operation the steam was superheated and the electrical input, W_t, noted. The wattage was then progressively decreased until a mist appeared on the walls of the sight glass and the new input, W_1, recorded. The heat required to dry one pound of steam was then:

$$H = K(W_1)/(W_t - W_1) \qquad (10)$$

where K was an experimental constant, depending upon P and T. The quality was found from:

$$X = (h_g - H)/h_{fg} \qquad (11)$$

While the technique described above eliminates flow measurements, errors in the estimation of the appearance of mist in the sight glass can influence final results by as much as 4 per cent (3).

Another version (25) of the electrical calorimeter makes use of thermocouples at the inlet and outlet piping of the instrument, connected in opposition. The steam sample is condensed and weighed; the electrical input is measured over the same time interval. When the thermocouples are in balance, the energy input, reduced to a unit weight basis, represents the heat needed to dry the steam.

The drying and metering functions are combined in another design (26) in which the steam passes through a calibrated orifice at exit. For such a unit the steady flow energy equation may be written:

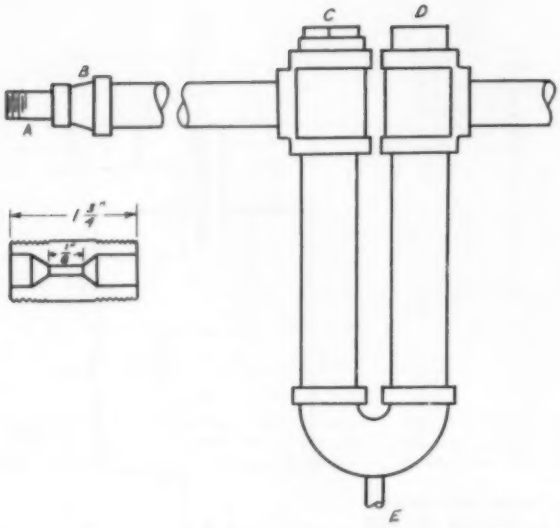

Fig. 6—Many successful throttling calorimeters can be made with only an assembly of standard pipe fittings such as this unit

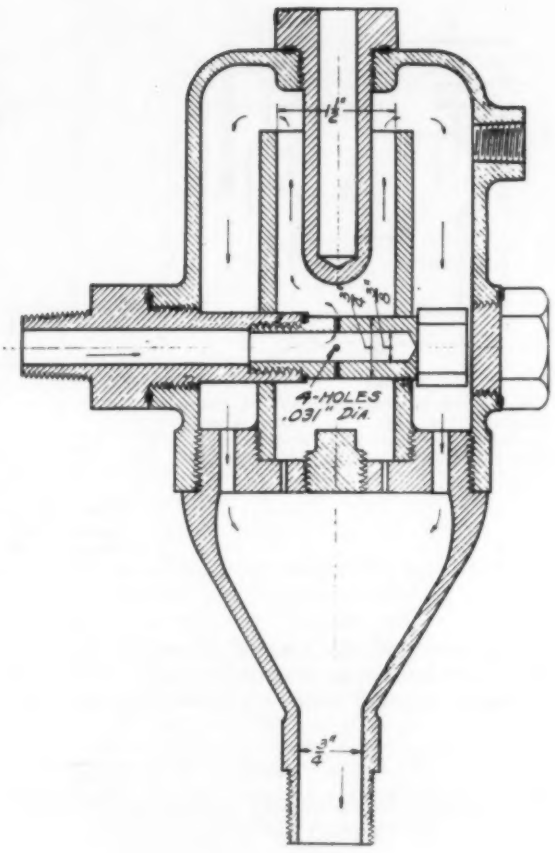

Fig. 7—Relatively few new calorimeter designs have been developed. This one houses the orifice in a removable cartridge for occasional cleaning and also employs steam as a radiation shield around the thermometer well

$$h_1 + Q = h_2 \qquad (12)$$

where Q represents the thermal equivalent of the electrical input, reduced to a unit weight basis, over the same time interval. The terminal enthalpy, h_2, must lie in the superheat region. If it does not, then the electrical input, Q, must be increased to effect this change. The quality may then be found from:

$$X = (h_2 - Q - h_{f1})/h_{fg1} \qquad (13)$$

Discussion

No effort has been made to assess the special calorimeters used in connection with circulation studies in steam generating equipment. This represents a highly specialized art which has been previously reported in this journal.

In the Appendix the principal U. S. Patents on steam calorimeters have been listed. It is interesting to note that there have been no new patents in this area for almost half a century. This reflects both the high state of the art and the lack of commercial significance of such instruments.

The wide use of superheated steam and the broad knowledge of steam properties have tended to reduce the importance of calorimetric measurements in industry. Where they are made, the instruments are frequently assembled from pipe fittings, as explained earlier.

Conclusions

Steam calorimetry occupies a classic position in thermodynamics and in the science and art of the generation and distribution of steam. Of the many forms of calorimeters proposed over the past ninety years, only the throttling and universal types are to be found in industry.

For the engineering student the study of calorimeters will continue to be important. The application of the steady flow energy equation and the consequences of throttling operations raise fundamental problems in the field of thermodynamics. Steam calorimetry should be presented in conjunction with the Joule-Thomson effect, stressing the value of throttling techniques in instrumentation.

Acknowledgments

The author wishes to thank D. C. Carmichael of E. I. du Pont de Nemours & Co. for the calorimeter design presented in Fig. 6. Professor J. A. Polson was most kind in supplying the drawing from which Fig. 7 was prepared. Professors E. H. Fezandie and G. F. Melick reviewed the manuscript and made several valuable suggestions.

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(26) "Determination of Quality of Low Pressure Steam," C. Stewart and J. L. Dilworth, *Southern Power & Industry*, w. 60r no. 2, Feb. 1942, pp. 85–89.

APPENDIX

Patent Literature on Steam Calorimeters

Patent Number	Inventor	Date	Type Calorimeter
401,111	G. H. Barrus	1889	Separating and throttling
492,710	R. C. Carpenter	1893	Throttling
494,057	R. C. Carpenter	1893	Separating
550,814	G. H. Barrus	1895	Throttling
575,391	R. C. Carpenter	1897	Separating
602,613	D. Baker	1898	Actually a pyrometer rather than a calorimeter
857,984	L. M. Ellison	1907	Throttling
898,610	C. C. Thomas	1908	Electrical, superheating
1,042,782	T. M. Gardner	1912	Jet impact used in a dubious manner to get a recorded dryness and/or heat content

Biennial Coal Show Held in Cleveland

The biggest event of the coal-mining world—the Biennial Coal Show of the American Mining Congress—was held in Public Auditorium, Cleveland, Ohio, May 13–15.

In one of the many technical papers **Loy A. Updegraff,** project engineer, Bituminous Coal Research, Inc., pointed out that increased mechanization of coal mines has brought about a step-up in the average coal output from six tons per man per day ten years ago to ten tons per man per day in 1956. While full seam mining had been made possible by increased mechanization and had boosted production of coal, however, it had also increased the problem of designing and building preparation plants capable of handling the increased amount of rejects and coal fines and of making a finished product acceptable to the market. Capital investment cost per ton hour of cleaning plant capacity has been rising steadily as the problem of cleaning and preparing the coal becomes more complex.

J. W. Bassett, mining engineer, West Kentucky Coal Co., described the operation of an all-belt haulage system for removing coal from the mine face underground to the outside. The use of all-belt haulage at mines of the West Kentucky Coal Co. has resulted in less than one per cent down-time from belt delays and an accident rate of next to nil. Belt haulage limits mining to that area which can be reached by the belt on hand and the method of mining and haulage tends to keep operating units close together and gives better supervision. In fact Mr. Bassett reported it is not uncommon for the assistant mine foreman to visit each of eight working sections four times each day.

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Abstracts From the Technical Press—Abroad and Domestic

(Drawn from the Monthly Technical Bulletin, International Combustion, Ltd., London, W.C. 1)

STEAM GENERATION AND POWER PRODUCTION

General

Testing of Boilers and Turbo-Alternators in Power Stations of the Central Electricity Authority. H. S. Horsman. *Proc. Inst. Mech. Engrs. 1956*, **170** (No. 18), 545–94.

Available methods are reviewed and a simplification of the deferred efficiency test as agreed with the Water Tube Boilermaker's Association considered. A table of average boiler losses in stoker and pulverised fuel firing is presented and from these reliable estimates of boiler performance can be deduced. Standardization of flow metering and improvements in technique are discussed.—From author's abstract.

Steam Generators

Steam Generator Designs. A. Bachmair. *BWK 1957*, **9** (Apr.), 167–9. (In German.)

Thirteen plants are in operation or under construction with operating temperatures of 1100–1200°F and the first supercritical unit, a Benson boiler rated at 560 klbs/h, 4850 psi and 1130°F, was recently started. Forced flow once-through boilers form 73% of all boilers of above 130 klbs/h ordered during 1956. Brown coal fired boilers with capacities of over 1000 klbs/h are now in operation; it is usual in these large units to divide the boiler on both the water and the gas side into two parallel systems so that in case of failure of one half or during overhaul the turbine can continue to run on half load. This design facilitates also starting and low load operation. Prefabrication of tube panels is increasing, especially in view of the high quality of welding required. Shell type boilers in sizes up to 20,000 lbs/h are equipped with mechanical stokers and have a thermal efficiency of 82–85%.

The Dewpoint in Oil Fired Boiler Plants and its Effect on Heating Surface Design and Operation. T. Geissler. *Energie 1957*, **9** (Feb.), 57–9. (In German.)

The dependence of the dewpoint of flue gases from oil fired boilers on the sulphur content of the oil is discussed. The oxidation of SO_2 to SO_3 is reduced by higher furnace temperatures, lower heat release rates and increased turbulence. The dewpoint can also be lowered by the addition of dolomite or ammonia. The economiser and air preheater should be designed so that temperatures below the dewpoint cannot occur; the minimum wall temperature should be not more than 18–54°F below the dewpoint. This can be obtained in the economiser by mixing water from the boiler drum with fresh feedwater at the economiser inlet, in air preheaters by preheating the air with steam, feedwater or boiler water or by recirculation of hot air. The minimum temperature to be adhered to can be taken from a diagram showing these temperatures as a function of the sulphur content of the oil.

The Water Circulation in Corner Tube Boilers. H. Vorkauf. *Energie 1957*, **9** (Mar.), 88–92. (In German.)

Model and large scale tests have shown that the water circulation in corner tube boilers is always positive. In boilers with differently heated tube bundles the circulation is improved if the tube bundles are connected in parallel with separate take-off of the steam-water mixture.

Solid Fuel Firing

Bituminous Coal Firing. W. Gumz. *BWK 1957*, **9** (Apr.), 169–71. (In German.)

The great majority of the larger boilers are equipped with furnaces with liquid slag removal because this permits the removal of the fly ash in granulated form; alternatively the fly ash is sintered in a separate plant. Cyclone firing results in higher thermal efficiencies and lower flue gas dewpoints. The number of boilers designed for combined firing of coal, oil or gas or other fuels is increasing rapidly. In stoker fired boilers ignition of the green fuel by inducing hot gases to pass over or through the incoming fuel is applied more often.

Liquid and Gaseous Fuel Firing

Oil Firing. O. Rosahl. *BWK 1957*, **9** (Apr.), 173–5. (In German.)

The reasons for the increased danger of low and high temperature corrosion in oil fired boilers are outlined. Low temperature corrosion can be prevented by ensuring that the wall temperatures of the economiser and air preheater do not fall below the dewpoint or by mixing additives to the combustion air or flue gases. No means of preventing high temperature corrosion are known in firing V containing oils which attack both ferritic and austenitic steels where the temperature exceeds 1100–1200°F. Fouling of superheaters can be reduced by widely spacing the tube banks, regular sootblowing and washing during operation. Heat release rates of oil fired furnaces should exceed those of pulverised coal fired furnaces by not more than 20–40% to prevent fouling.

Experience in the Combustion of Heavy Fuel Oils in Steam Generator Plants. O. Rosahl. *Mitt. V.G.B. No. 46, 1957* (Feb.), 13–27. (In German.)

The literature on the experience with oil firing in boiler plants is reviewed and supplemented by the author's own investigations. The main themes discussed are: (1) Low temperature corrosion and dewpoint phenomena and the dependence of the dewpoint on firing arrangements and boiler load; very good results have been obtained with oil firing in cyclone furnaces where dewpoints of 60°C (140°F) have been measured at 40% of full load; (2) High temperature corrosion and the influence of vanadium; this must be regarded as more serious as it will be more difficult to find measures to counteract the effect of V_2O_5 on steel and refractories; the addition of dolomite has brought relief in some but not all cases; (3) Fouling of heating surfaces by oil ash deposits; in many cases fouling has been severe and a comparison with coal ash has shown that the constituents of the oil ash become volatile at a lower temperature (1300°C) than those of coal ash; especially the critical fouling temperature (850–1000°C) is considerably lower than that of coal ash; (4) Deposits on convection pass heating surfaces, dust separators etc.; deposits of soot during starting up may lead to air preheater fires and frequent sootblowing or water washing should be carried out; (5) Consequences for the design and operation of oil fired boilers; the design should be similar to

Before World War II COMBUSTION regularly featured as a department "Steam Engineering Abroad." This present abstract series appearing above for the first time, it is hoped, will service some of the interests that department met as well as give a ready reference to the more salient reports in today's technical press.

coal fired boilers and dimensions should not be reduced; during starting and stopping it may be advisable to use a bypass around the air preheater; (6) Classification of fuel oils; this should be done according to V, S and H_2O content, ash and alkali content; a preliminary grouping of oils according to V and S content from European, Asian, American and Near East sources is presented.

Changing the Properties of Deposits on Heating Surfaces of Oil-fired Boilers by Using Admixtures. N. M. Knyazev, A. V. Sinyavskii and M. G. Starikov. *Elekt. Stantsii, 1957*, **28** (Jan.), 22–5. (In Russian.)

From an examination of data obtained from a medium-pressure thermal station on the combustion of sulphur-containing fuel oil and measures adopted for modifying the properties of deposits formed on heating surfaces it is concluded that the addition of reagents changes the physical and chemical properties of fuel-oil ash, lime and dolomite in particular improving the constitution of the deposit and lessening the aggressive nature of the ash. The additions can be fed through a channel separate from the fuel feed. Reduction in acidity of the deposit raises its neutralising capacity and must bring about a fall in dewpoint.—From *C.E.A. Digest 1957*, **9** (Apr. 13), 971.

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Swiss Experiments with Oil Fired Boilers. H. Vogler. *Mitt. V.G.B.* No. *46, 1957* (Feb.), 37–9. (In German.)

In boilers for oil firing Sulzer install cast iron air preheaters and water sprays for washing in service. Despite this, corrosion occurred in the coldest parts since the recirculation of preheated air was not applied although provision was made for it. Experiments with adding dolomite have not yet been conclusive.

Operational Experience with Oil Firing in Marine Boilers. W. Behrens. *Mitt. V.G.B. No. 46, 1957* (Feb.), 40–5. (In German.)

Corrosion of air preheaters has not been very frequent and can be reduced by washing in service. Hard deposits on superheaters can be avoided by regular washing with water under high pressure.

Experience with Dolomite Addition to Oil Firing. G. Nyberg. *Mitt. V.G.B. No. 46, 1957* (Feb.), 45–7. (In German.)

At the Öresundsverket Power Station 3 kg dolomite ground to 80% below 125 μ is added per m^3 heavy bunker "C" oil containing 3–4% S. This reduces the dewpoint temperature from 185°C (365°F) to 155°C (311°F) in the hotter parts of the air preheater and from 125°C (268°F) to 55°C (133°F) in the colder parts. The air is preheated in a low pressure steam heat exchanger from 30–40°C (86–104°F) to 60–70°C (140–168°F). If no dolomite is added the air preheater is clogged up rapidly.

Heat Tracing of Pipelines. Anon. *Pwr. and Wks. Engng. 1957*, **52** (May), 169–75.

The heating of oil-carrying pipes by electricity, steam and hot water is described and the basis for selecting one or the other medium discussed. Generally, electric tapes are used up to pipe length of 400 ft, mineral-insulated, metal-sheathed cables up to 1500 ft and steam or hot water for longer lines. The equations necessary for calculating external steam and hot water tracers and for selecting the correct tracing cable are given.

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Water-Side Corrosion and Water Treatment

Hydrazine and its Use in the Treatment of Boiler Feed Water. G. Genin. *Chal. et Industr. 1957*, **38** (Mar.), 57–70. (In French.)

A broad review is presented of: (1) Methods of hydrazine preparation; (2) Properties of hydrazine and its compounds; (3) The use of hydrazine for the removal of oxygen from water; (4) Advantages of the use of hydrazine; (5) Methods of its use.

Flue Gas, Ash and Dust

The Mechanical Engineer's Contribution to Cleaner Air. Anon *Engng. Boil. Ho. Rev. 1957*, **72** (Apr.), 126–30.

Abstracts are given of the nineteen papers presented to the Conference organised by the Institution of Mechanical Engineers under the following headings: (1) Who will pay for cleaner air? (2) The role of the engineer; (3) Air pollution control in large boilers; (4) In-built features of large boilers; (5) Smokeless combustion with pulverised fuel boilers; (6) Smokeless combustion with cyclone furnaces; (7) Smokeless combustion with large oil fired boilers; (8) Boiler design features which make for cleaner gas emission; (9) Equipment to prevent emission of grit, dust and sulphur dioxide; (10) Prevention of grit, dust and smoke emission from industrial boilers; (11) Instruments and automatic control; (12) Education and training of boiler operators; (13) The cost of air pollution.

Power Generation and Power Plant

Martins Creek Exceeds Expectations. W. H. Kopenhaver. *Coal Utilization 1957*, **11** (Mar.), 23–9.

Since the station is intended for peak operation with a low annual load factor steam pressure and temperatures are moderate and no reheat is used to keep capital costs low. Up to now two twin-furnace boilers each rated at 1200 klbs/h, 1325 psi and 955°F and two 132.5 MW turbogenerators have been installed. Two ball mills per boiler pulverise 32.25 tons/h of coal to a fineness of 82% through the 200-mesh screen. Twelve burners are installed in the front wall of each furnace in two horizontal rows, each row being served by one mill. The furnace front wall constitutes the radiant superheater, the

convector superheater is installed behind the slag screen and is followed by twin economisers and the air preheater. Ash and slag in the furnace hopper are removed hydraulically, fly ash from the hoppers underneath the economisers, air preheater and precipitator pneumatically. The average thermal efficiency of the steam generators during two years operation has been 90.7%, the coal rate 0.81 lb/kWh and the net heat rate 10,890 Btu/kWh.

Design for Fast Pick-Up. D. V. Kelley and W. M. Pickslay. *Elect. World 1957*, **147** (Apr. 1), 56–9.

At the Humboldt Bay Plant the boiler and turbine unit is designed to produce full load in three seconds from the initial standby load of 5%. For this reason the oil fired boiler is of two-drum design and has a capacity of 475 klbs/h at 900°F, the temperature being guaranteed over a load range of 20–100%. The pressure at minimum load is 1050 psi and this is reduced to 850 psi at full load to store heat during the time required to increase the firing rate to full load. For the same reason the steam separating drum is larger than usual. The turbine generator is rated at 50 MW.

INSTRUMENTS AND CONTROLS

Automatic Data Logging—A Step Closer to the Automatic Plant. Anon. *Power 1957*, **101** (Apr.), 73–9.

Automatic recording systems and their application to power station operation are described.

Computer Tapes Lb Coal/kWh. A. Bur. *Elect. World 1957*, **147** (Mar. 25), 94–5, 156.

At the Cleveland Electric's Lake Shore Power Station a computer is installed which counts the number of times the batch scales have weighed 400 lbs of coal during the time 40,000 kWh have been generated. The ratio of lbs coal per kWh is arrived at automatically and the result recorded continuously.

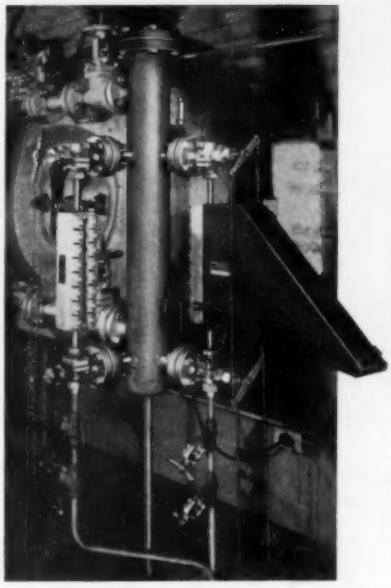
Automatic Control Systems for Forced Flow Once-through Steam Boilers. Siemens-Schuckertwerke A.G. British Patent 771,715, Germany, July 12, 1954.

The operation of the boiler is controlled as a function of the load, the controller actuating the water, fuel and air supply. In addition the temperature at a pre-determined point of the tube system is maintained at a desired temperature by control of the feed water supply, the desired temperature being adjustable as a function of boiler load.

Insure safe, continuous boiler operation with

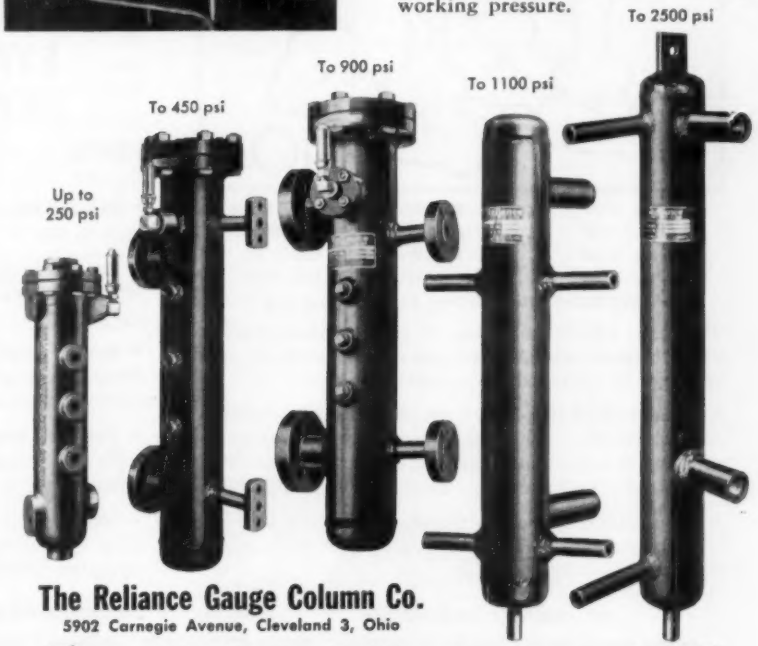
Reliance

Water Columns



Water columns have been around for a long time — ever since Reliance introduced the first one in 1884. Its chief reason for existence then was to carry the float-operated whistle alarm and mechanism, to warn operators of dangerously low water in the boiler. Since then, the water column has been developed in various styles and capacities to meet any power plant need. They are used on most boilers today as an accepted necessity, although many old time engineers — and thousands of young ones — can't explain their full usefulness. If you'd like to know "why a water column", write for free copy of our Liquid Level Letter No. 11.

Reliance makes Water Columns in seven pressure categories, five of which are represented below. And complete "trim" — gage cocks, gage valves, gage inserts, special gages and direct-to-drum assemblies. Write for information on equipment suited to your working pressure.



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The name that introduced safety water columns....in 1884

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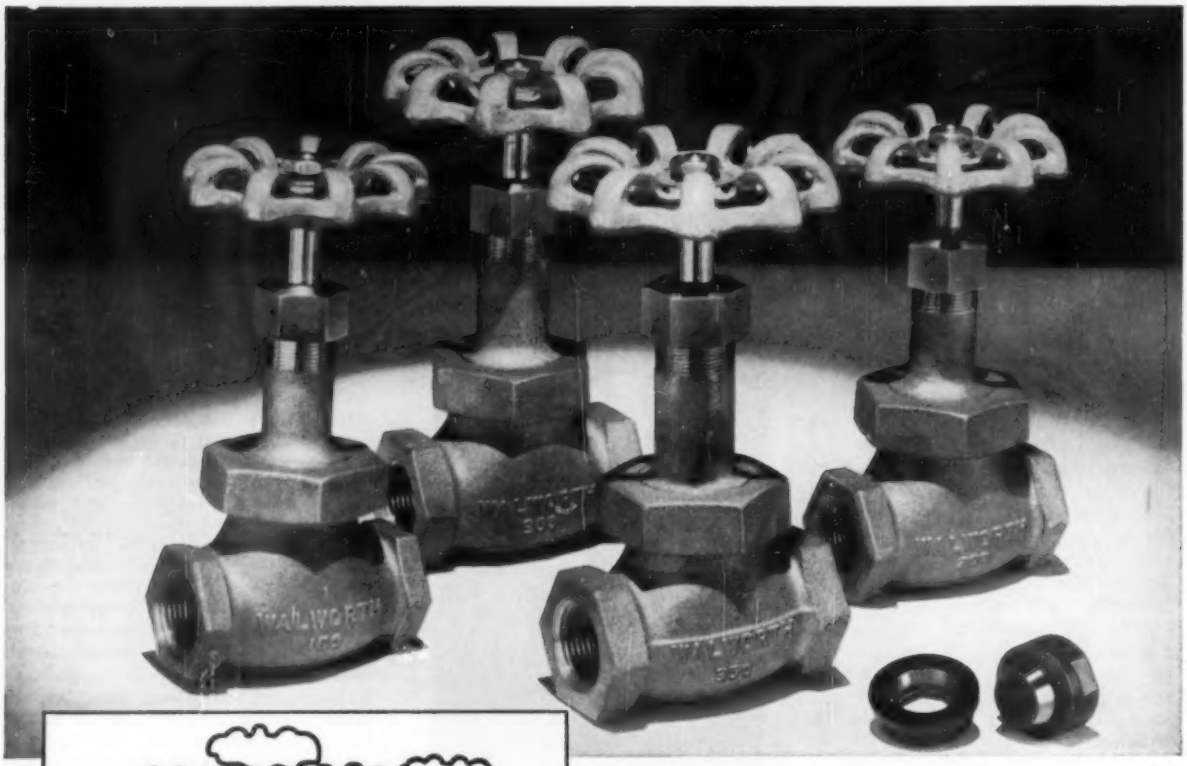

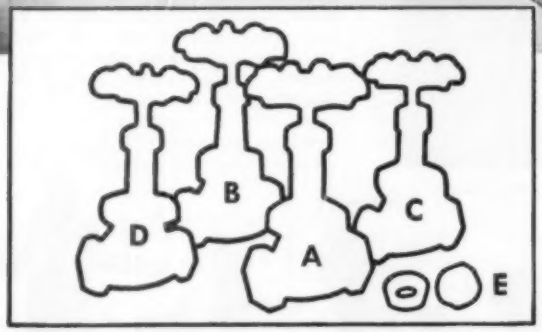

A — No. 225P. . . . . 350 WSP 550F, 1000 WOG
B — No. 260P. . . . . 300 WSP 550F, 600 WOG
C — No. 245P. . . . . 200 WSP 550F, 400 WOG
D — No. 237P. . . . . 150 WSP 500F, 300 WOG
E — "500 Brinell" Stainless Steel Plug Type Seat and Disc

Walworth offers four lines of Bronze Globe Valves with stainless steel, plug-type seats and discs. Advantages of these valves include:

• **Stainless Steel Plug-Type Seats and Discs,** heat-treated to a minimum of 500 Brinell hardness reduces wire-drawing to a minimum. Seats and Discs are machined and fitted simultaneously, assuring perfect mating.

• **Deep Stuffing Boxes with Glands** are fitted with reinforced, molded packing. Valves can be repacked under pressure when fully opened.

For Longer Bronze Valve Life . . .

"500 BRINELL" PLUG-TYPE STAINLESS STEEL SEATS AND DISCS

150 lb. 200 lb. 300 lb. 350 lb.

• **Oversize Stems,** made of high tensile strength silicon-bronze, assure long life.

• **Rugged Body Hexes,** are flat on top; do not interfere with wrench gripping body-to-bonnet union ring connection.

• **Bodies,** made of Composition M bronze (ASTM B61), have ample wall thickness to provide high safety factor.

• **Patented Handwheels** are air-cooled and designed with a "finger-fit grip." Makes turning easy even when wearing greasy gloves.

• **Identification Plates** secured by lock-washer under stem nut, show Figure Number of valves and make re-ordering sure and easy.

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. . . ANSWERING YOUR QUESTIONS ABOUT

Apexior Number 1 for boilers

®

HOW MUCH CLEANING IS NECESSARY BEFORE APEXIOR-COATING?

A surface no cleaner than good operating practice demands is all the foundation needed for Apexior Number 1 — the coating that ever after holds steel at newly cleaned efficiency.

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By saving man-hours that might be expended needlessly. A quick, three-step check tells when cleaning has delivered just-right surfaces, prepared neither less nor more than necessary.

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DOES CHEMICAL CLEANING AFFECT APEXIOR?

In no way. Rather, Apexior takes on the added function of preventing acid-metal contact and the resultant attack, however slight, that might occur. Those engaged in chemical cleaning report that Apexior speeds the process by keeping deposits few and less tenacious.

WHEN SHOULD A BOILER BE APEXIOR-COATED?

To seal water-contact surfaces permanently at highest efficiency and take them safely through the initial shake-down period, a new boiler should be Apexior-coated immediately after erection; an operated boiler, immediately after cleaning.

IS APEXIOR BOILER COATING DIFFICULT?

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HOW LONG DOES APEXIOR LAST?

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This message — one of a series — presents more reasons why Apexior Number 1, first used inside boilers in 1906, is today manufactured in the United States and four foreign countries to meet world-wide demand for protection of

- *boiler tubes and drums*
- *evaporators*
- *deaerating and feedwater heaters*
- *steam turbines*

MAINTENANCE FOR METAL

THE DAMPNEY COMPANY

HYDE PARK, BOSTON 36, MASSACHUSETTS

205

Allis-Chalmers Pumps Meet Power Plant Requirements

Continuous Condenser Service at Detroit Edison's River Rouge Plant

At River Rouge Station, these Allis-Chalmers 84 by 60-inch circulating pumps, driven by 500-hp motors, deliver 73,000 gpm to the A-C condenser.

They play an important part in assuring service continuity at this station. An accurately cast impeller, hand finished and dynamically balanced, assures smooth operation. Other features, including a rigid whip-free shaft, and tube-protected shaft and rubber bearings lubricated with filtered water, have made A-C circulating pumps popular throughout the power industry.

Many customers use Allis-Chalmers test facilities to properly design their intake structures.

You Get **MORE** than a Pump . . . When You Specify Allis-Chalmers

You can take advantage of Allis-Chalmers wide experience in supplying pumps to all industries. You are assured of modern design, heavy-duty construction and correct application aid — all adding up to many years of dependable service.

Allis-Chalmers is the only company that can offer you "One-Source" responsibility, with a complete unit — pump, motor and control — all built to work together. For "MORE" information about Allis-Chalmers pumps, call your local A-C office, or write Allis-Chalmers, General Products Division, Milwaukee 1, Wisconsin. A-5216

ALLIS-CHALMERS

New Edward Instrument Valve *with integral hard-faced seat ends corrosion-erosion problems!*

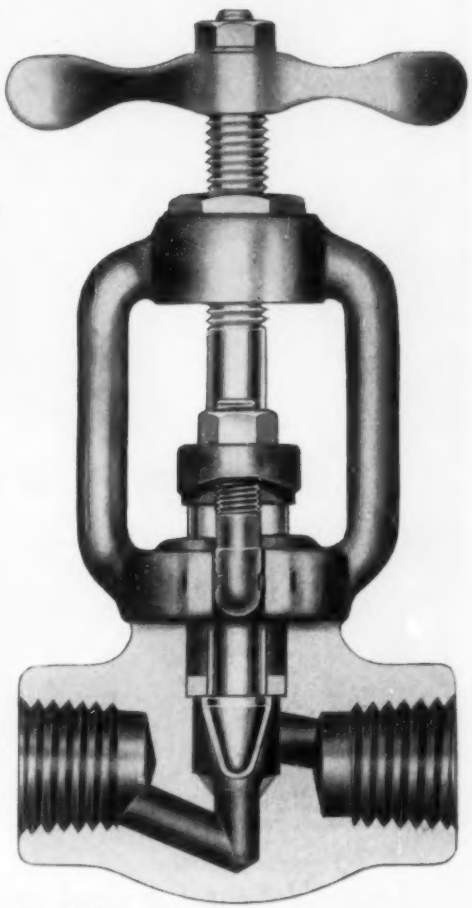

Fig. 952

Used to be, you had to choose between valves of stainless steel—which were difficult to weld into carbon steel pipelines—and valves of carbon steel, which soon corroded and began to leak around the seat. Scientists in the Research Laboratories at Edward Valves, Inc., have been hard at work on this common, costly, irritating problem. And—as usual—they have come up with the solution.

Valve seat now hard-faced with cobalt-chromium-tungsten alloy

This new Edward instrument valve combines a carbon steel body with a cobalt-chromium-tungsten seat face for long, dependable, corrosion-resistant life. *The seat is integral with the body to eliminate leak problems.* Precision machining of the alloy seat—in the same set-up as the body bore—is followed by careful lapping to form drop-tight mated seating faces with 100% bearing surface. The carbon steel body permits easy, efficient welding into carbon steel pipelines. Screwed ends are also available.

Precise flow control

Precise flow control is achieved by tapered needle point stem disk and fine pitch screw threads. This new Rockwell-built Edward instrument valve meets the need for a small, compact stop and variable flow valve for high-pressure, high-temperature service. Rated at 2500 lb. at 850F., the new valve is ideal for all power plant instrumentation. The stainless steel body line will continue in production for applications requiring extreme corrosion resistance.

For further information on the new Edward instrument valve, write for Bulletin 571.

Edward Valves, Inc.

Subsidiary of

ROCKWELL MANUFACTURING COMPANY

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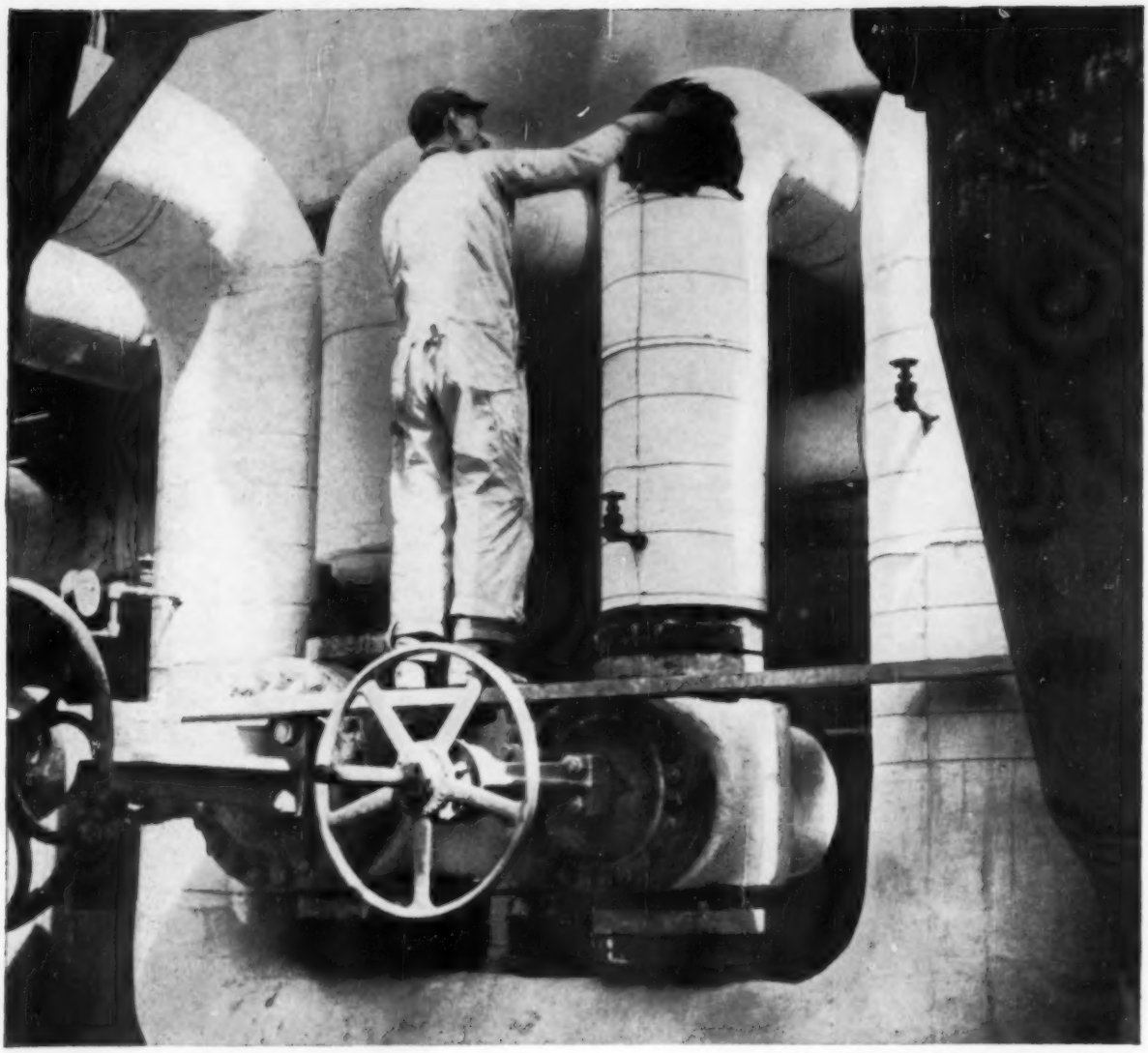

J-M 85% Magnesia offers excellent workability . . . from application to finished coat.

Install lasting fuel savings and lower maintenance costs

. . . with J-M 85% Magnesia insulation!

At temperatures to 600F, no insulation is so widely used, or so closely associated with economy and increased operating efficiency as 85% Magnesia. Any wonder, then, that 71% of insulation maintenance engineers responding in a recent survey made 85% Magnesia their first choice in its temperature range.

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To assure you maximum value in insulation application, Johns-Manville offers you complete planning and job-site service . . . practical recommendations by the world's most experienced insulation engineers, backed up by expert installation by J-M Insulation Contractors.

Write today for further information on Johns-Manville 85% Magnesia Insulation. Address Johns-Manville, Box 14, New York 16, N. Y. In Canada: 565 Lakeshore Road East, Port Credit, Ontario.

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Saving Fuel at Appliance Park

★ General Electric Company at its Appliance Park Boiler House, Louisville, Ky. has found that Bailey Controls help to save fuel by continuously maintaining desired operating conditions.

With a Bailey-engineered control system you can count on a high output of available energy per unit of fuel.

Here's why:

1. Suitable Equipment

When you receive equipment recommendations from a Bailey Engineer his selections come from a complete line of well-engineered and carefully tested products.

2. Seasoned Engineering Experience

Your local Bailey Engineer brings you seasoned engineering experience based on thousands of successful installations involving problems in measurement, combustion, and automatic control.

3. Direct Sales-Service—close to you

For your convenience and to save time and travel expense there's a Bailey District Office or Resident Engineer in or close to your industrial community.

For greater fuel savings, less outage and safer working conditions, you owe it to yourself to investigate Bailey Controls. Ask a Bailey Engineer to arrange a visit to a nearby Bailey installation. We're glad to stand on our record.

A128-1

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for Cutting Steam Costs

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\+ Bailey Engineering
\+ Bailey Service
= Greater Savings per Fuel Dollar

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Complete Controls for Steam Plants

BAILEY METERS
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FEED WATER
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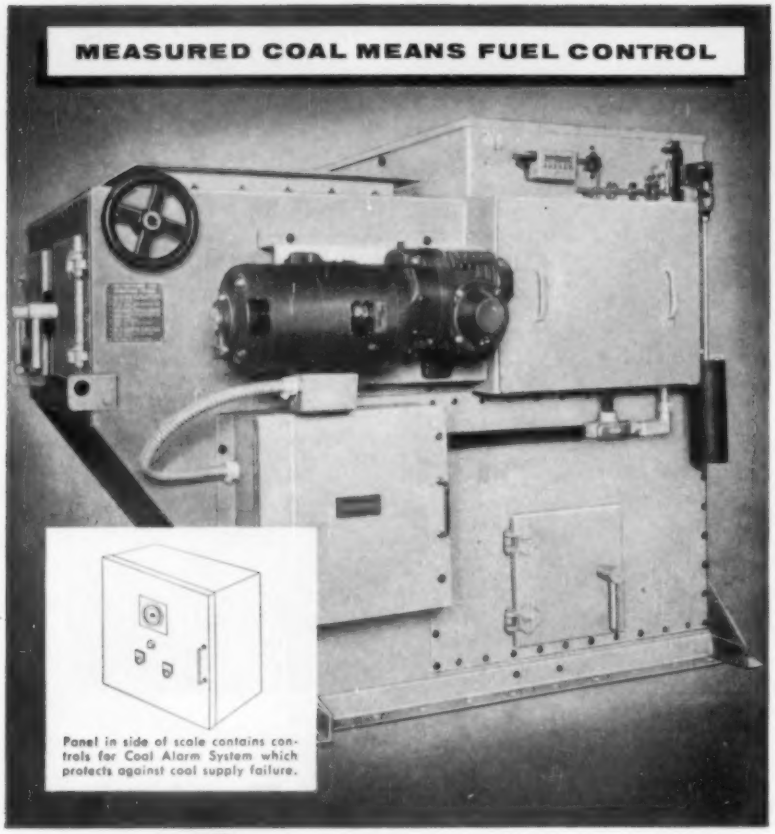
MEASURED COAL MEANS FUEL CONTROL
Panel in side of scale contains controls for Coal Alarm System which protects against coal supply failure.

Richardson H-39

AUTOMATIC COAL SCALE

saves you money through dependable, efficient, safe operation

Latest in the series of Richardson Automatic Coal Scales, the H-39 is available in two sizes: a 200-pound model with an hourly capacity of up to 20 tons and a 500-pound model with an hourly capacity of up to 40 tons. Here are some of the reasons why it is specified throughout the world by industries that demand outstanding quality and superior operation.

- Large 24" x 24" inlet (standard for all models) so coal moves through freely. Coal never "arches" in an H-39 feeder or weighing hopper.
- All contact platework of stainless steel.
- All parts of scale positively dust-sealed.
- All electrical equipment totally enclosed and installed outside of dust-proof housing, so it is never in contact with coal dust at any time.
- Endless belts available.
- Feeder removable.

For further information, write for bulletin 0352-A.

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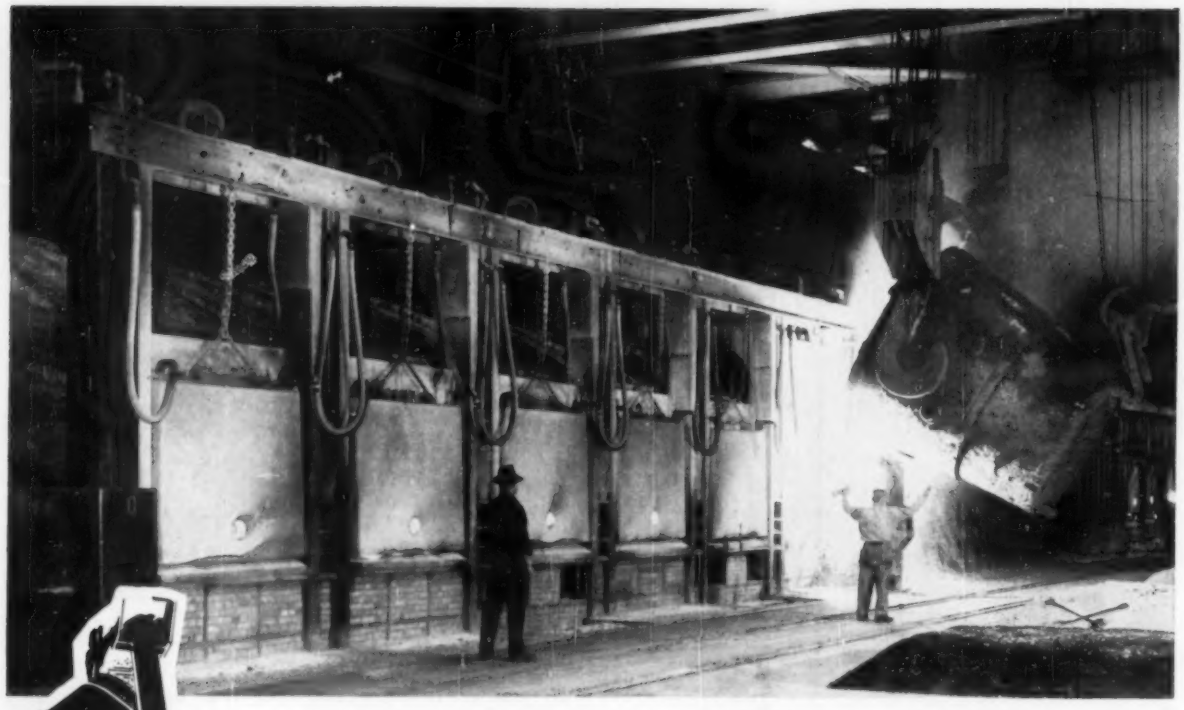

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600 TONS– enough steel in each heat for 300 automobiles. That's the capacity of Weirton Steel Company's new open hearth furnace at Weirton, W. Va. Weirton Steel is a division of National Steel Corporation.

Designed and built by Loftus Engineering Corporation, Gateway Center, Pittsburgh, this giant is completely automatic in operation.

As for so many other impressive installations, Clarage equipment was selected – a Clarage induced draft fan for the waste heat boiler and a Clarage forced draft fan for the furnace.

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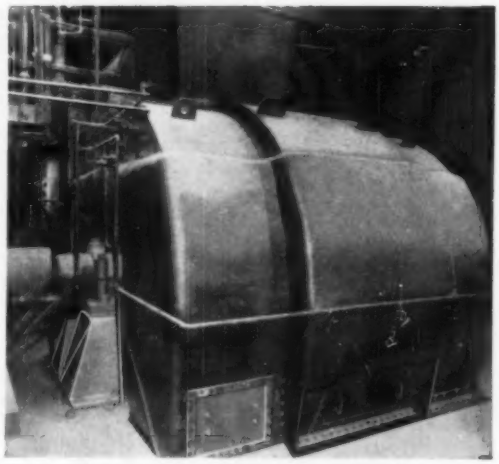

Clarage heavy-duty fan provides induced draft for waste heat boiler.

CLARAGE ... *dependable equipment for making air your servant*

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IMPROVED BLOWER NOZZLE

another important feature of the

New **Diamond** **Series 300 IK**

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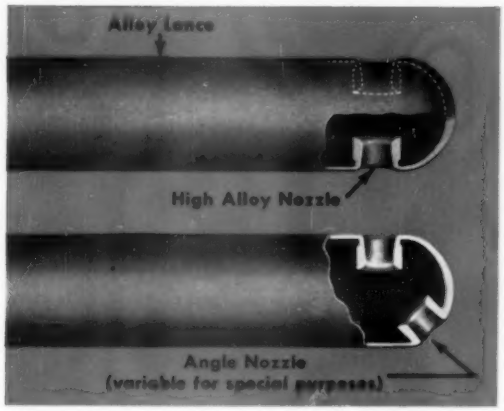
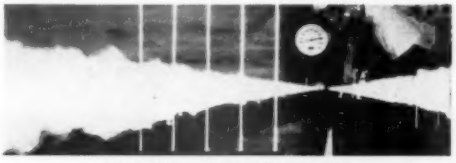


This improved nozzle provides more available cleaning energy per pound of steam or compressed air. A modified venturi, it is the result of extensive research during which more than 50 contours were tested.

This feature is one of many reasons why the Diamond Series 300 IK Blower does a better and more economical job of cleaning surfaces which require a long retracting blower. Other advantages are listed at the bottom of the page. Ask the nearest Diamond office or write directly to Lancaster for Bulletin 2111V which will tell you much more about the new Series 300 IK.

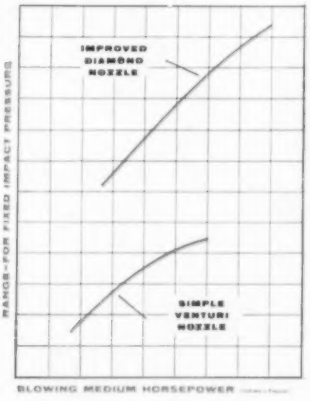
Improved Diamond Type "A" Nozzle has low approach velocity for optimum nozzle performance (see curves below). It provides greatest impact for any given blowing pressure . . . means greater effectiveness and economy.



IMPROVED DIAMOND NOZZLE

SIMPLE VENTURI NOZZLE

Note the greater blowing range of the improved Diamond Nozzle when compared with a simple venturi nozzle under identical test conditions.



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WESTERN PRECIPITATION

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Optimum Precipitator power input is maintained regardless of operating conditions. The sensing control is simple, positive, accurate—and automatically evaluates the spark "Power Value" (intensity and frequency)—not just frequency or intensity alone.

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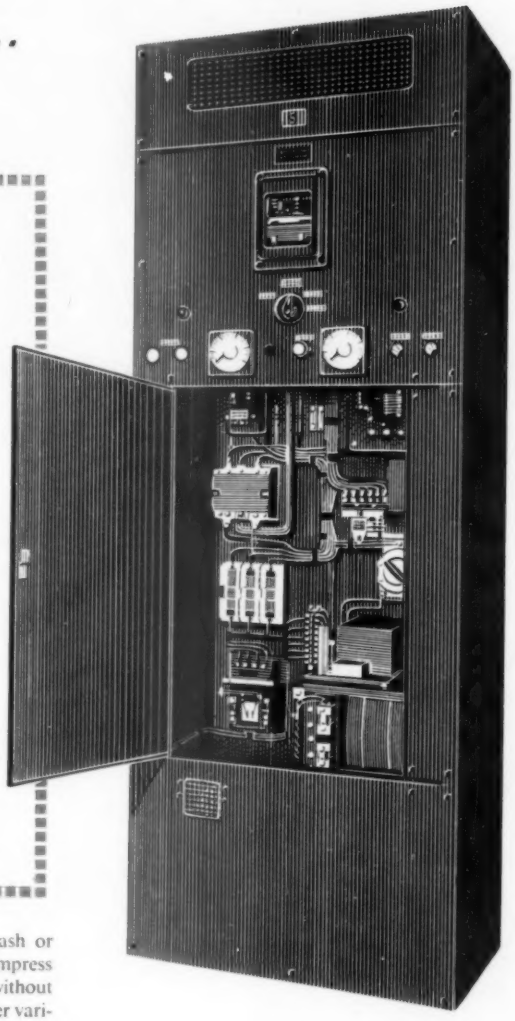
Under short circuit, open circuit or other varying conditions, this control is completely stable and inherently trouble-free!

4 MODEST COST

Modest initial cost coupled with negligible maintenance assure optimum operating efficiency (therefore lower operating costs) throughout many years of continuous service.



WHEN using a Cottrell Precipitator for collecting dust, fume, fly ash or other suspensions from industrial gases, it is essential at all times to impress on the high voltage system the highest possible voltage and current without "flashover". Depending upon gas conditions, dust loading and other variable factors, the optimum voltage and current requirements vary widely from one minute to the next. Therefore, the vital importance of a simple, trouble-free and highly sensitive Precipitator Control is self-evident.

This new Western Precipitation Automatic Precipitator Control—*a product of the organization that has consistently led in the application of Cottrell Precipitators for industrial gas cleaning*—combines vital advantages found in no other competitive equipment. Our nearest representative will be glad to supply complete details. Or write direct!

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MULTICLONE Mechanical Collectors
CMP Combination Units
DUALAIRE Reverse-Jet Filters
HOLO-FLITE Processors